August 2015

The Blue Castle Project:

A Feasibility Study of the Proposed Nuclear Power Plant in Emery County, Utah along the Green River

Department of Civil & Environmental Engineering
THE UNIVERSITY OF UTAH

EXECUTIVE SUMMARY

The Blue Castle Project is a proposed plan to enable the construction and operation of a new nuclear power production facility near Green River, Utah. The parent organization for the Project—Blue Castle Holdings Inc.—is currently conducting federal licensing and state planning exercises to analyze costs associated with new base load electric power generation while accounting for a variety of project criteria, including: energy market access, available transmission capacity and new corridors, water resources availability, appropriate physical and geological site characteristics, supportive local and regional communities, and attractive overall site realization potential.

This Report was prepared by University of Utah students enrolled in *CVEEN 3100: Technical Communications for Engineers.* Students enrolled in *CVEEN 3100* during the Spring 2015 semester identified various aspects of the proposed project that presented the most significant challenges from a civil and environmental perspective. Students worked in teams to compile feasibility reports, which comprise the individual chapters. Teams coordinated with one another to ensure that research content, images, and technical data discussed in one chapter did not overlap with material in other chapters.

Chapter 1 "Project Overview and Economic Analysis" offers a synopsis of the Blue Castle Project while introducing the facility and discussing the economic impacts it will have for the State of Utah. In order to meet projected energy growth demands in Utah, Chapter 2 "Utah's Energy Use and Resources" examines the potential expansion of local resources by analyzing traditional, alternative, and renewable energy sources and comparing how these producers might satisfy future energy needs. Chapter 3 "AP1000 Reactor System: Details and Specifications" describes the essential components and technical specifications of the AP1000, such as the reactor core, coolant, and power generation, while proffering an overview of how nuclear reactors operate. Chapter 4 "A Case Study of the Vogtle Power Plant for the Blue Castle Site" conducts a case study of the Vogtle Nuclear Power Plant located in Burke County, near Waynesboro, Georgia to provide a better understanding of the design and layout of the proposed Blue Castle site plan and the functions of its key buildings.

Perhaps one of the greatest concerns of any nuclear facility from an environmental and safety perspective involves water; thus, Section IV "Hydrologic Aspects of the Facility begins in Chapter 5 "Legal Aspects and Acquisition of a Water Right" with an investigation of numerous facets of water use, including: legal considerations and procurement of a water right, design of the diversion works to convey water to the plant, and environmental effects of that water diversion. Chapter 5 gives an overview of the Section, considers the legal process of acquiring a water right for Blue Castle Holdings Inc., and, finally, describes each step of the water right application process. Chapter 6 "Water Resources: Supply and Effluent" furthers the work of Chapter 5 by analyzing and designing a potential system to transfer water into and out of the plant into an evaporation pond. Chapter 7 "Environmental Impacts: Ecology, Air, and Water" examines how the proposed plant will affect local ecosystems on the Green River, both in the long and short term as well as the impacts on human health and mitigation strategies.

Chapter 8 “Site Safety, Operations, and Security Protocols” discusses three major aspects of the Blue Castle Project, namely: security, safety, and operations. The security portion details both physical and cyber security measures taken to protect a nuclear power plant; safety is examined in terms of regulatory changes following the Fukushima disaster and their relation to the Blue Castle Project; and the operations component analyzes the role daily procedures play in meeting the overall safety goals of the facility. Similarly, Chapter 9 “Nuclear Waste: Treatment and Disposal Techniques” interrogates the public’s role in determining whether the project will move forward or not while also accounting for what nuclear waste containment may look like in the not-so-distant future

Chapter 10 “Geotechnical Report: Site Feasibility” conducts a geotechnical investigation and makes recommendations on soil feasibility for development of nuclear power plant while Chapter 11 “BCP Feasibility Report Conclusions” concludes the Report with a Decision Matrix Score for the project from the class’s perspective.

EDITOR'S PREFACE

This feasibility study is one of a two-part series that investigates large-scale, civil works projects in the Western United States. Both studies occurred in the 2014-2015 academic year as part of *CVEEN 3100: Technical Communication for Engineers* offered in the Fall and Spring semesters by the Department of Civil and Environmental Engineering. This Report, along with the prior—*The Uinta Express Pipeline: A Comprehensive Research Report Conducted by Students Enrolled in CvEEN 3100 Technical Communications Report* (February 2015)—is housed within the USpace Institutional Repository at the J. Willard Marriott Library on the University of Utah campus (pending review). Both reports were researched and written by students as part of their final course grade; I simply facilitated the research design and compiled the individual chapters once they were finalized. I firmly believe that student-led research is an important, and underutilized, aspect of civic engagement since it is not motivated by (overt) political or industry pressures. Thus, these students should be commended for their efforts at understanding and contributing to the ongoing dialogue that will shape our collective future.

As this Report is a compendium of student writing, I have made every effort to maintain the tenor and style of their work. At times, however, I have made minor revisions and omissions from the original drafts. Any changes I have made occurred within three general categories: redundancy, language use/grammar, and formatting.

> **Redundancy** Occasionally, certain words or phrases would appear either out of context or in an inopportune place such as a title or subheading. The most common example of redundancy occurred with the phrase Blue Castle Project or BCP.
>
> **Language use/Grammar** While compiling the Report, a grammatical error would appear, and I indiscriminately accepted/rejected certain changes. I must be clear: I did not *proofread* the document; rather, I would make a trivial change if I happened upon it.
>
> **Formatting** The most significant edits I made involved formatting and organization. Occasionally a chapter was numbered incorrectly and I manually changed the numbering to ensure for overall consistency. Such changes no doubt have affected in-text referencing, etc. Other instances occurred when a sentence or passage needed to be shortened so that subheadings laid out correctly. In each case, I tried to maintain the integrity of the original, while editing only as much as required of final copy.

This Report represents a serious attempt by undergraduates to combine the technical writing skills we studied in the course of a semester with the expectation and level of expertise required of civil and environmental engineers. The students, for their part, were professional, serious, and intelligent, and I am immensely proud of the work they accomplished.

Joshua B. Lenart, Ph.D.
Salt Lake City, UT
August 2015

TABLE OF CONTENTS

Cover Image: The Green River, Emery County, Utah, United States, undated.

Photo Credit: BitHead, flickr.

Chapter 1

Project Overview and Economic Analysis

Abstract
With an increasing population in Utah, specifically in the Salt Lake Valley, the demand for energy is rapidly growing each year. Currently, Utah's electric grid is largely produced by burning coal, natural gas, and other fossil fuels. In the past, supplying Utahns with electricity from these forms has been sufficient, but with the predicted rise in population, there is a need for more efficient production methods. The established energy infrastructure in Utah is not only harmful towards the environment, but does not have the capacity to keep up with the demand in the upcoming years. For those reasons, a safe, more secure, and reliable form of power will have to be explored.

Blue Castle Holdings Incorporated, an energy infrastructure development company has proposed the construction of a nuclear power plant. The facility, based around a reactor design by Westinghouse Electric Company, will be built in Emery County, Utah near the Green River. The reactor will be fueled by a uranium core and cooled by water obtained from the river. The proposed facility has the potential to double Utah's current electricity production.

The second part of the chapter will examine the financial implications of the prospective power plant. Initial planning and licensing will be funded by Blue Castle Holdings. This includes; water rights, property title, facility design, and protocol. Their intention is to sell these components to a prospective buyer who will construct, operate, and maintain the power plant. The building costs of the facility will be provided by major investors, taxpayers and energy subsides provided by the government. After completion, revenue from the nuclear plant will benefit Utah by stimulating the local economy, improving environmental quality, and exporting excess energy to neighboring states.

1.1 Project Proposal

The Blue Castle Project was proposed by Blue Castle Holdings Inc. (BCH) in 2007. The nuclear power plant will be located in Emery County, five miles north of Green River, Utah. The facility will use water from the Green River to pressurize and cool the uranium cores. Upon completion, the facility will be the newest nuclear power plant in the United States and will supply Utah residence with a surplus of 1,116 Megawatts of energy to the electric grid. This will cover 50% of Utah's electric energy demand [1]. The excess energy will be sold to the surrounding states such as California, Arizona, and Nevada. The nuclear facility will be equipped with the world's most technologically advanced reactors designed by Westinghouse Electric Company (WEC). The innovative design of the facility will eliminate potential risks associated with nuclear power and lead to a safer, more sustainable, energy source.

Figure 1.1: Location of Proposed Site.

1.1.1 Challenge for Change

As of 2011, Governor Gary R. Herbert projected the State of Utah will experience a total energy growth of 52.3% until the year 2020 [2]. This is largely attributed to the increase in population that Utah is estimated to experience during this time. Herbert projected that electric energy production alone will need to increase by 19.1% in a 10 year period, see Table 1.1 for Utah's projected energy growth.

Current energy infrastructure in Utah will not be able to meet this projected growth. In response, Governor Herbert established a 10 year plan, *Energy Initiatives and Imperatives*. The plan states current Utah energy production is comprised of 46.7% coal burning, 39.9%, natural gas and 12.2% crude oil [2]. This means that 98.8% of Utah's energy infrastructure and production is dependent on nonrenewable resources which leaves the State of Utah in a vulnerable position due finite lifespan of these reserves. With this legislature, Herbert hopes to ensure Utah's continued economic and societal growth by developing new cutting-edge energy technologies to meet the demand. In particular, sources that enable Utah to utilize natural resources with an elevated environmental consciousness.

Table 1.1: Governor Herbert's Energy Initiative: Utah's Projected Growth.

Utah's Projected Fossil Fuel Energy Growth–Next 10 Years.
Source: Rocky Mountain Power, Questar, Utah Geological Survey

	2011	2020	Percent Change	Annual Rate
Electricity Load (RMP) (MW)	4700	5600	19.1%	1.9%
Natural Gas (Questar) (million Dth)	170	200	17.6%	1.8%
Petroleum/Transportation (mbbl/yr)	45	52	15.56%	1.15%

In 2014, President Barack Obama proposed the *All-of-the-Above Energy Strategy* which promotes America becoming more energy independent and efficient. By 2030, the initiative vows to cut carbon emissions in the United States by 30% [3]. A large percentage of nonrenewable energy sources will be replaced with safer and environmentally focused form of energy. The use of renewable resources, such as wind, hydropower and nuclear energy, will be key in the implementation of these plans. To follow through with the “all-in approach” to energy innovation, Obama called on Congress to make the current renewable energy Production Tax Credit permanent and refundable [3]. This will create incentive and certainty for investors to back new clean energies.

1.1.2 Stakeholders

The largest contributor in the development of the Green River nuclear facility is BCH, an energy infrastructure development company out of Orem, Utah. The company’s mission statement is, “select, acquire, enhance, and license plant sites which are uniquely well suited for the deployment of new nuclear power generation” [1]. In the proposition of the Blue Castle Project, BCH is obtaining water rights, land titles and facility blueprints. Once planning is complete, BCH will sell the rights to an investor who will construct, maintain and operate the plant. The management team for the company includes many influential professionals such as the former chairman of the U.S. Nuclear Regulatory Committee (NRC), past state legislators, former nuclear industry executives, and the former general manager of the Intermountain Energy Agency (IEA). Two executives of BCH are Aaron Tilton, the CEO and former republican lawmaker, and Nils Diaz, the Chief Strategic Officer and former NRC chairman [4].

Another contributor is Westinghouse Electric Company (WEC). Based out of Pittsburgh, Pennsylvania, WEC is the largest supplier of nuclear plant products and technologies in the world. In addition, WEC has equipment in approximately one-half of the world's operating nuclear plants [5]. WEC has a long history in the nuclear industry and is responsible for the design of the first commercial Pressurized Water Reactor (PWR), released over 50 years ago. Not only does WEC provide reactor design, but they also offer automation, fuel and continual updated plant engineering, to ensure the highest level of safety and efficient operation. Their designed reactor for the Blue Castle Project, the AP-1000, has gone through over 20 years of research and development, and is a simplified version of their original reactor the AP-600 [6]. This reactor is use in most nuclear facilities around the world. The AP-1000 has been designed to prevent failures seen in previous nuclear disasters. It encompasses multiple passive emergency systems that do not need personnel action to implement safety features in the case of an emergency.

Not only do private companies have a major impact in the proposed nuclear facility, but the State of Utah is also a crucial contributor to whether or not this facility will eventually be built. For the construction of the facility, many parts of the state government are involved for certain approvals. The State of Utah and BCH have worked closely with each other to finalize water right allocations for the facility and for the residents of Emery County. Kent Jones, a Utah State Water Engineer, was the first government official to facilitate movement towards the construction. Jones approved water rights from the Green River in both Kane and San Juan Water Conservancy Districts to use for the facility [7]. The State is primarily concerned about how the construction of this project will impact Utah.

The State of Utah’s influence on the proposed facility has also extended into the judiciary branch. In 2005, Judge George Harmond was appointed by Gov. Jon Huntsman Jr. to serve as the Seventh District Judge. Judge Harmond serves Emery, Grand, San Juan, and Carbon Counties, two of which have leased water rights to BCH for the operation of the Blue Castle Project [8]. Before accepting the role of Seventh District Judge, Harmond was a member of the Utah Board of Water Resources for two years. During Harmond's tenure, a lawsuit was filed by Healthy Environment Alliance of Utah (HEAL), which attempted to overrule his decision to grant water rights to BCH. In a 26 page memorandum decision, Harmond ruled that the water BCH was seeking for cooling the reactor and storage, had already been approved for the use of a coal power plant. This plant was never constructed, leaving unused water rights from Kane and San Juan County. Harmond stated that the court received no evidence to prove the water had a more beneficial use. The use of water for production of power is considered just as advantageous as irrigation or use by the public [9]. Thus, BCH acquired the lease for these water rights.

1.1.3 Nuclear Facility

As mentioned the Blue Castle Project is proposed to be constructed in Emery County, located five miles northwest of Green River. The facility consists of two nuclear reactors, both of which are AP-1000's, designed by WEC. The design is based on a pressurized, gravitational, hydraulic system that uses water from the Green River and uranium as the main source of energy. The engineers who produced the schematics stressed the importance of the simplification of the AP-1000 system from the original PWR. The intention was to reduce the number of parts within the facilities, in order to reduce the number of potential problems and failures. The footprint reduction is roughly 5x smaller than that of the PWR, seen in Figure 1.2. Nuclear fission is the process of generating nuclear energy bombarding a large uranium isotope (U-238) with a smaller isotope (U-235). The collision causes the larger isotope to break apart into two elements, Barium (Ba) and Krypton (Kr). The energy emitted by this collision is used to generate steam. The steam turns a turbine which powers a generator to produce electricity [10].

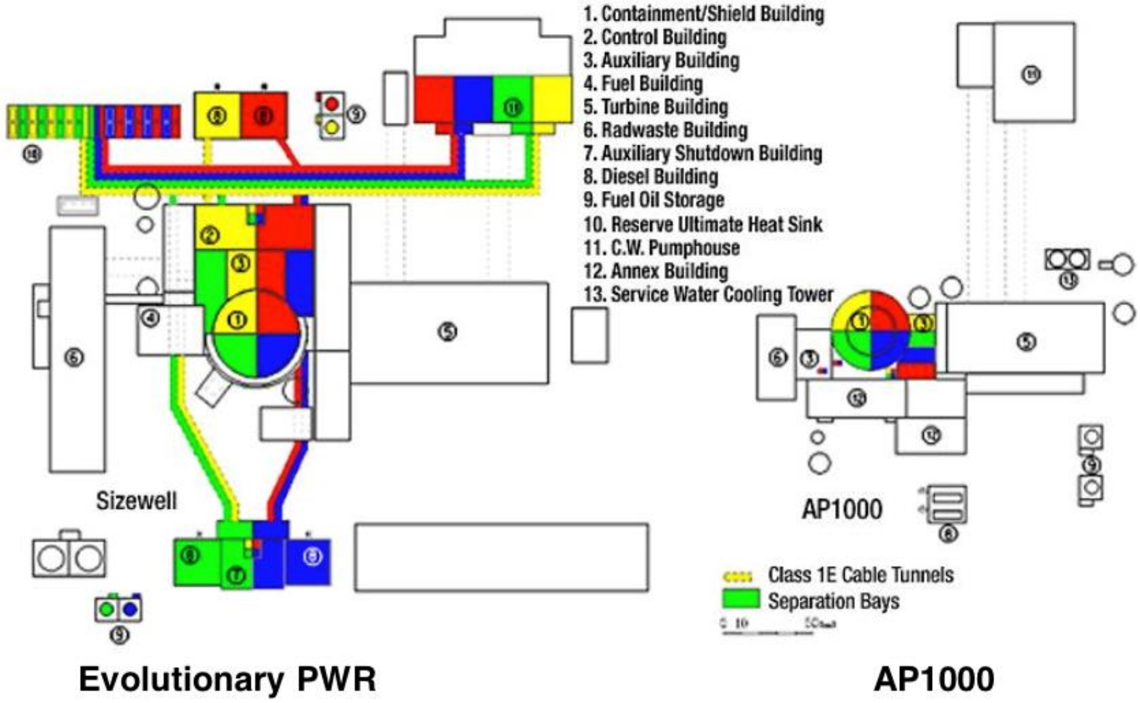


Figure 1.2: Reactor Innovation: Footprint Reduction.

There are eight nuclear facilities under construction, in China and in the United States, that house the first AP-1000 reactors [11]. The best comparison to use in understanding the impacts of the prospective facility, in Green River, is to study Plant Vogtle in Waynesboro, Georgia. Plant Vogtle's initial construction was completed in the late 1980's and was designed for future expansion. The plant consisted of two AP-600's known as Vogtle 1 and 2. As of 2009, Georgia Power is adding two AP-1000 reactors to Plant Vogtle's infrastructure [12]. The safety features of the AP-1000 reactor have been improved from reactors in the past because it utilizes active and passive safety control systems.

1.1.3a Water Resources

In the operation of the nuclear plant, the use of water to cool and pressurize the uranium core is crucial. The need for water rights from the Green River, as well as a mode of water transportation to obtain the water, is imperative for the design and operation of the plant. Water rights have been acquired by BCH from the State of Utah at this time. The approval of water rights grants the plant 53,600 acre-feet of water per year, a mere fraction of the 4.4 million acre-feet per year that flows through the Green [7]. The application process to obtain these rights required approval from both Kane and San Juan County Water Conservancy Districts. The transportation of the water from the river to the nuclear reactor will require a pipeline and a pumping system to be developed. The reactor will also require a pipeline to transport spent water to a 50 acre evaporation pool on site. All of which are to be specified by seasonal river flow rates and rainfall projections.

1.1.3b Potential Risks

Concerns regarding the safety of nuclear power have largely been at question simply due to the toxic elements used to generate the energy. The mass public is aware of the negative impacts that can occur if nuclear facilities are not operated with proper safety measures. For example, the partial core meltdown that occurred at the Three Mile Island nuclear reactors in Dauphin County, Pennsylvania and the tsunami that hit Japan which caused the Fukushima Daiichi Nuclear Power Plant to leak harmful radioactive material into the atmosphere [13]. Risks of how the Blue Castle Project will affect the Green River and the surrounding counties will be taken into account during the construction of the facility. The risks involved in this project include: proper treatment and disposal of spent uranium, environmental impacts of flora and fauna, and proper safety protocols in case of an emergency. The production of nuclear radiation and nuclear waste at these facilities can largely affect the ecosystem. Due to potential hazards, the design, construction, and operation of the facility will utilize the most recent technologies regarding safety to ensure the public that all precautions are being considered.

The design of the AP-1000, along with the facility it is housed within, has been through over 20 years or research and development and encompasses the most innovative passive and active safety systems on the market. Past nuclear catastrophes have allowed designers to learn from mistakes and malfunctions and design a system with up to three back-up systems for a multitude of emergency scenarios.

In case of power loss to the reactor, the plant encompasses multiple back-ups to ensure cooling of the core. Active systems include: redundant safety-related DC batteries, which support an ‘up-to-code’ safe shutdown for 72 hours, two 80 kW diesel generators, housed on-site, which can supply cooling water to the facility for four days. In addition, two 4 MW diesel generators are able to run the entire facility for seven days in case of a blackout. Passive emergency measures include: magnetic control rod release to halt uranium reactivity, gravity facilitated water storage tanks for 72 hours of core and facility cooling, a secondary water storage tank, run by the diesel generators for an additional four days of stabilization, and multiple safety injection systems that depressurize the system and slow the reaction in case of power loss or failure of the automated pressurizing systems [14].

In the isolation of Utah’s desert, the only imperative design consideration for a natural disaster is for earthquakes. The plant in Green River lies within a 200 mile radius of over 44 fault lines [15]. The NRC requires strict guidelines for facility design and safety in case of such an event. Title 10 of the Code of Federal Regulations (10 CFR) has all licensing for engineering practices and includes “safety margins” that should be factored into the building of the facility. The NRC has classified the Green River site as a Seismic Category I and II facility. This categorization requires that the facility must retain the integrity of the structure in case of a safe shut down as well as the safety systems must continue to perform its safety related function. The law states that the facility in this category must design for 0.3 g's of ground acceleration in order to meet standards. Due to the relatively high potential of an earthquake, BCH installed a seismographic monitoring station at the proposed site in January of 2014. The station was implemented as a part of the NRC requirement, but furthermore for engineers to enhance the overall safety of the facility [16]. The AP-1000 has been designed for a Review Level Earthquake (RLE). RLE standards state the facility must retain structural integrity for an acceleration up to 0.5 g’s of force. This overdesign has given the structure a 95% confidence interval with regards to function and makes the facility safe in the occurrence of actual catastrophe [17].

After the terrorist attacks on September 11, 2001, the NRC passed a new regulation called the 50.150 Aircraft Impact Assessment. This requires all nuclear facilities to perform a design-specific assessment, which analyzes the implications of the collision between a large commercial aircraft and the nuclear facility. The facility must then be constructed or retrofit in case of a terrorist attack. The design must follow two stipulations with reduced operator action: the core of the reactor must remained cooled or contained and the spent fuel storage stays intact [18].

1.2 Economic Analysis

The cost of nuclear energy, but more importantly the economic impact of the Blue Castle Project for Utah is unpredictable. The nuclear facility being proposed is a new technology which makes projected construction cost unreliable. Due to this uncertainty, nuclear energy lacks the necessary funding from the private sector which ultimately affects the consumer of the energy produced. In comparison to the Vogtle 3 and 4 reactors being constructed, Georgia Power estimates that customers will see a 6 to 8% increase in rates. These increased rates come due to the financing of the facility but also the benefits that nuclear energy provides [12]. As nuclear energy reemerges with significant advancements in the construction and safety implementation, the cost of nuclear energy will begin to decline due to increased public awareness and the attraction of investors. However, since nuclear energy carries the stigma of catastrophe, the impact to the recreation industry, a major contributor to Utah's economy, faces potential impact in reduction of outdoor related activity around the nuclear facility.

1.2.1 Planning and Licensing Costs

Since the Blue Castle Project is still in the planning stages, there are no exact costs for the facility at this time. However, BCH has invested $17 million and is planning on spending at least another $100 million [19]. Nuclear energy is not cheap and the money spent on the Blue Castle Project so far is strictly for planning and licensing. In fact, the price of constructing a nuclear facility can only be estimated due to the longevity and complexity of the project. Plant Vogtle is the best comparison to the Blue Castle Project and is currently projected to cost $16.5 billion upon completion. Vogtle 3 and 4 are an expansion of a currently operational nuclear facility. Some economic reviews consider expansions to have lower construction costs than building an entirely new facility [20]. Nevertheless, the cost of Vogtle 3 and 4 has progressively increased as construction continues. The original projection for the Plant Vogtle's expansion was $14.3 billion but due to cost overruns and design changes, the current total cost is $15.5 billion [19]. Each change that occurs during the planning, licensing, or construction phase of a nuclear facility results in an unpredicted rise in cost.

1.2.2 Delegation of Funds

Due to the uncertainty of nuclear energy, investors have been hesitant to finance the industry. Wall Street is an example of a major sector that will not invest in nuclear energy. Because of the lack of major financial support, the cost of nuclear energy remains high. As more facilities are built, the cost associated with nuclear energy will gradually decrease. Due to the increased frequency and familiarization of constructing nuclear facilities, construction costs will see a major decrease. In addition, competition for building these massive structures will increase and ultimately lower the cost due to specialization required by contractors. While the construction of facilities is more practical, public support of nuclear energy will develop into understanding the immense benefits.

The cost of constructing a nuclear facility is calculated based on an idea known as overnight cost. The concept of overnight cost factors out the financing aspect of the project and focuses strictly on construction. Engineering-Procurement-Construction (EPC) and owner's cost are the two components that make up overnight cost. The EPC is the cost of labor and the equipment for the facility to be built. The owner's cost has nothing to do with what is commonly known as construction or the process of building. Owner's cost are actual components of the facility [20]. A further breakdown of overnight costs are shown on Table 1.2.

Table 1.2: Breakdown of Construction Costs.

EPC Costs	Owner's Costs
Labor	Land
Overtime	Materials
Equipment	On-site Facilities

Maintenance	Licenses
Specifications	Administration

For a project of this magnitude and complexity, the costs of operating and maintaining a safe environment are much higher than standard energy generation facilities. Due to the fact that the power is harnessed from nuclear fission, additional costs will factor into the total expenditures of the facility. Nuclear energy power plants are a considered a high liability work environment. This calls for more specialized employees, hazard pay, and costs for the transportation and handling uranium. The uranium for the Blue Castle Project will come from a mine approximately 135 miles from the facility. White Mesa Uranium Mine, owned and operated by Energy Fuels, is conveniently located in the San Juan County and is the only fully-licensed uranium mine in the United States [22]. Instead of importing uranium from other states or countries, Blue Castle Project will be able to support the local economy as well as cut down on the transportation costs.

According to the U.S. Energy Information Administration (EIA), as of 2013 the net price of natural occurring uranium was $44.65 per pound and the total expenditures related to the land, exploration, drilling, production, and reclamation of uranium was $309 million [23]. Figure 1.2 graphically represents uranium prices as nuclear power has become more popular. The AP-1000 nuclear reactor, offers designs and modifications that extend the fuel lifespan to 18 months [24]. This cuts down on the overall consumption of uranium and lowers the fuel cost compared to previous reactor designs.

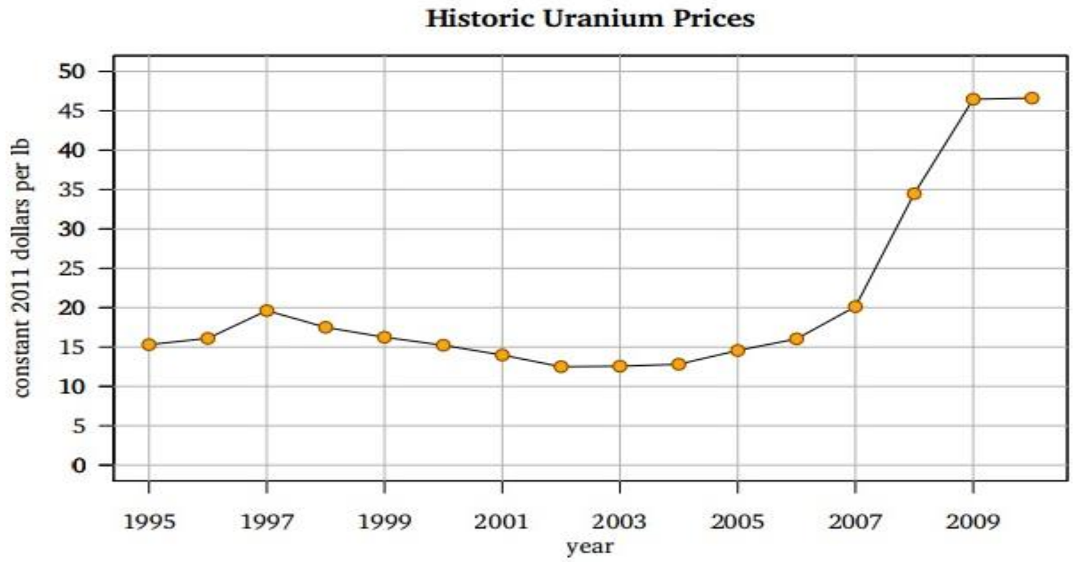


Figure 1.3: Historic Uranium Prices.

Another factor in the operational costs of the facility is the specialization of the employees working there. When a job requires specialized employees, their salaries and benefits goes up. Costs regarding technical training of employees and insurance of the facility, ultimately have an influence in total operational costs. In the case of a nuclear power plant, workers exposed to hazardous material, like uranium, increases the company's liability. Hazard pay means “additional pay for performing hazardous duty or work involving physical hardships” [25]. The U.S. Department of Labor (DOL) mandates workers compensation for employees working with hazardous material in the form of hazard pay.

Routine maintenance is essential in keeping a nuclear facility operational. When first licensed, a facility is considered operational for up to 40 years as long as constant regulatory criteria are met with regards to safety and protocol. After the facility has reached the initial 40 year lifespan, a license renewal can be filed with the NRC for an additional 20 years. According to the Nuclear Energy Institute (NEI), the nuclear industry collectively spent $1.7 billion in routine maintenance for new or reconditioned equipment in 2013 [26]. In addition to routine maintenance cost, the nuclear industry also invested over $3 billion to upgrade current facilities after the Fukushima failure [27]. As technology has assisted the progression of nuclear energy, the NRC is currently in the process of reevaluating their regulatory process that directly relates to safety by finding a more efficient way of evaluating facilities. Regulations have only become stricter over the past three decades, yet these regulations have made nuclear facilities safer for the public, environment, and those who work near the reactors.

1.2.3 Financial Impact of Nuclear Energy

Upon the completion of the Blue Castle Project, Utah's energy infrastructure will be completely transformed. Not only will Utah become a cleaner state in regards to energy production, but the nuclear facility is estimated to contribute $535 million to the local economy annually [20]. Since the Blue Castle Project will produce an excess of energy, the surplus will be sold to surrounding states. Eventually, the growth of Utah will demand all of the energy produced from the nuclear facility.

As nuclear energy becomes the cleaner and more reliable source of energy in Utah, the coal and oil industry will be severely affected. Currently, there are estimated to be 3,700 jobs related to coal production and consumption in Utah. As of 2014, the Deer Creek Coal Mine in Emery County shut down resulting in 182 employee layoffs [28]. Coal mine closures will continue in coming years as society moves towards cleaner energy. In addition, the federal government is pulling their subsidies from coal and oil companies and investing them in new energy technology [3]. Many effects of the coal industry are illustrated in Table 1.3. Public perception of energy production from the burning of coal and oil has changed significantly in recent years. As the public becomes more educated about the negative effects of current energy sources on human and environmental health, support for safer, more renewable, and cleaner methods of energy will increase [29].

Table 1.3: Effects of Coal Industry.

600+	U.S. Coal Plants
67	Air Toxins from Coal
200,000	Coal-Triggered Asthma Attacks (2010)
$345 Billion	Annual Cost of Coal
20-30	Years of Recoverable Coal
0	Coal Plants Built Since 2008
100+	Coal Plants Defeated by Activists

The final concern associated with the construction of a nuclear plant, is its potential economic implication on the outdoor recreation industry in Southern Utah. Outdoor recreation contributes more than $5.8 billion dollars to the State's economy, and drives the $7.4 billion dollar tourism industry [30]. Due to the plants prospective location in Emery County, there is a great deal of both local, government and public, concern upon its impact on recreation in the area. The site has three National Parks within a 100 mile radius, and is located alongside Utah's largest recreation and tourism attraction, the Green River. Although BCH has assured that the likelihood of a nuclear catastrophe is unlikely, there is always a possibility, and safety protocols should not be taken lightly. Currently, the construction of the plant is not projected to have a significant impact on the recreation economics. Although, there is still concern about education of the public since many believe that the mere existence of the plant would affect the river. This could initially hinder the amount of tourism seen in Southern Utah upon completion of the plant.

1.3 Conclusion: Economic Review

At this point in time, Blue Castle Holdings has provided the necessary funds for planning and licensing. Although funding for the Blue Castle Project is not finalized, due to the increased support and government backing of nuclear energy, obtaining the finances for the facility is plausible. In addition, Blue Castle Holdings has proven to the State of Utah that they are financially capable of completing the process planning and also proper licensing required to construct a nuclear facility. Based upon the economic review of the Blue Castle Project and case studies from similar facilities, the proposed nuclear plant construction is feasible.

Implementing nuclear power in Utah will have a large effect on current energy producing methods. As Utah's non-renewable reserves are being depleted, and cleaner energy solutions are being developed, existing industries will see a decrease in efficiency as well as funding and public support. Chapter two, *Energy Needs and Demands,* will analyze the current dependency of energy production, and how it will be affected by the implementation of the Blue Castle Project.

1.4 References

[1] “About: The Blue Castle Project,” [Online]. Available: http://bluecastleproject.com/about.

[2] G.G.Herbert, “Energy Initiatives and Imperatives,” Gov. Office., Salt Lake City, UT, Mar. 2011.

[3] P.B.Obama, (2014) “Clean Power Plan,” [Online]. Available: https://www.whitehouse.gov/energy/climate-change.

[4] “About: BCH Management Team,” [Online]. Available: http://bluecastleproject.com/about.

[5] “About: Westinghouse,” [Online]. Available: http://www.westinghousenuclear.com/About.

[6] “New Plants: AP-1000 PWR,” [Online]. Available: http://www.westinghousenuclear.com/New-Plants/AP1000-PWR.

[7] Department of Natural Resources. (2014). State Engineer Approves Applications to Use Green River Water for Nuclear Power Plant. State of Utah. Available: http://www.waterrights.utah.gov/pressRelease/greenRiverNuclearPowerPressRelease.

[8] "Judge's Biographies," State of Utah, 27 March 2014. [Online]. Available: https://www.utcourts.gov/judgesbios/showGallery.asp?dist=7&ct_type=D. [Accessed 27 April 2015].

[9] H. J. G. M., "Memorandum Decision," State of Utah, Seventh Judicial District Court, Emery County, 2013.

[10] "How Do Nuclear Plants Work?," Duke Energy, [Online]. Available: http://www.duke-energy.com/about-energy/generating-electricity/nuclear-how.asp. [Accessed 25 April 2015].

[11] Westinghouse, (2015) “New Plant Engineering and Construction,” [Online]. Available: http://www.westinghousenuclear.com/New-Plants/Engineering-Construction.

[12] “Plant Vogtle Units 3 and 4,” Georgia Power: A Southern Company, Waynesboro, GA, 2015.

[13] "Fukushima Accident," World Nuclear Association, (February 2015). [Online]. Available: http://www.world-nuclear.org/info/safety-and-security/safety-of-plants/fukushima-accident/. [Accessed 25 April 2015].

[14] “AP-1000 Overview,” WEC, Pittsburgh, PA, 2011.

[15] "Earthquake Fault Information & Country Fault Maps," Utah Geological Survey, [Online]. Available: http://geology.utah.gov/hazards/earthquakes-faults/utah-faults/earthquake-faults/. [Accessed 26 April 2015].

[16] “Seismic Station Installed at Proposed Nuclear Site,” *The Current,* Jan, 2014.

[17] “AP-1000 Nuclear Power Plant,” WEC, Pittsburgh, PA, 2011.

[18] U.S. NRC. *50.150 Aircraft impact assessment.* [Online]. http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0150.html.

[19] J. Fahys, "Utah Gives Green Light to Nuclear Power Plant," *The Salt Lake Tribune,* 20 January 2012.

[20] M. T. Hogue, "A Review of the Costs of Nuclear Power Generation," *Economic and Business Review,* vol. 72, no. 1, pp. 1-16, 2012.

[21] K. C. W. C. District, "Minutes of the Board of Trustee," in *Board of Trustees Kane County Water Conservancy District General Meeting*, Kanab, Utah, 2014.

[22] "White Mesa Mill," Energy Fuels, [Online]. Available: http://www.energyfuels.com/white_mesa_mill/ . [Accessed 25 April 2015].

[23] "Domestic Uranium Production Report," U.S. Energy Information Administration, Washington, DC, 2014.

[24] "New Plants: Improved and More Efficient Operations," Westinghouse, [Online]. Available: http://www.westinghousenuclear.com/New-Plants/AP1000-PWR/Operations-and-Maintenance. [Accessed 25 April 2015].

[25] T. E. Perez, "Hazard Pay," United States Department of Labor, [Online]. Available: http://www.dol.gov/dol/topic/wages/hazardpay.htm. [Accessed 26 April 2015].

[26] N. E. Institute, "License Renewal of Nuclear Energy Facilities," Nuclear Energy Institute, Washington D.C., 2015.

[27] T. A. P. Institute, "Energy Tomorrow," Washington D.C., 2015.

[28] M. Gorrell, "Emery County Mine to Shut Down; 182 Losing Their Jobs," *The Salt Lake Tribune,* 15 December 2014.

[29] "Coal: Dangerous Power," Energy Justice Network, [Online]. Available: http://www.energyjustice.net/coal. [Accessed 25 April 2015].

[30] G. Herbert. (2013). *Office of Outdoor Recreation* [online]. http://business.utah.gov/programs/outdoor/.

Chapter 2

Utah's Energy Use and Resources

Abstract
Renewable energy is a crucial demand for nations around the globe. Having multiple sources of energy is a necessity for present and future generations. The need for extensive developments and large investments requires the availability of a great amount of energy. The electricity system consists of the relationship between the generation, transmission, distribution systems, supporting capital markets and the end users. Utah's primary energy sources are coal, natural gas, petroleum and hydro-electricity. These abundant in-state resources have returned a relatively low cost on a high standard of living; however, Population growth and a technologically dependent society will increase energy demand and prices. Also, the state's natural resources are limited and may run out in the near future with the current rate of use. Currently renewable and nuclear energies are the only known sources of energy that are not affected by diminishing supplies. This report examines many energy issues including how we use energy, where our energy comes from, how the production and consumption impacts us, and determining if the Blue Castle Nuclear Power plant is a viable option for Utah's future.

2.1 Introduction

Renewable energy is a crucial demand for nations around the globe. Having multiple sources of energy is a necessity for present and future generations. The need for extensive developments and large investments requires the availability of a great amount of energy. In one of the steps towards meeting the rising demand for electrical power, Utah is in the process of building a nuclear power plant. Safe, secure, and reliable is the motto for Utah's nuclear plant. Nuclear energy's advantages include environmentally friendly, cheap electricity, efficient, and reliable. However, it is necessary to investigate the necessity of a Nuclear Power plant. In order to do this, it is practical to determine what are the actual energy demands of the current population as well as what the predictions are for the future. In addition the current energy producers need to be examined to determine if they are not sufficiently handling the energy demands. From this, we can then determine if the risks of operating a Nuclear Power Plant are necessary.

2.1.1 An Overview of Current Energy Consumption and Production in Utah

The quality and type of life that people have depend mainly on energy. The use and consumption of energy depend on many factors like prices, availability, and efficiency. Being one of the fastest growing states, the rate of energy

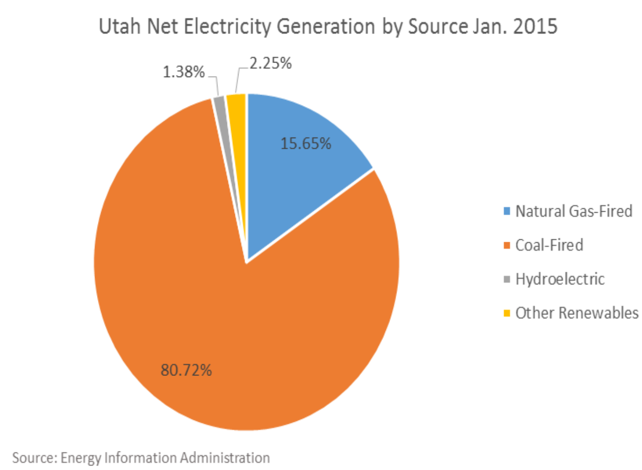


Figure 2.1: Shows Utah electricity generation by source.

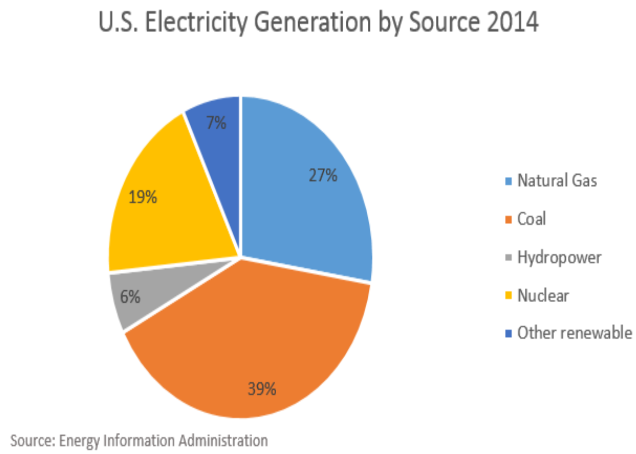


Figure 2.2: Shows US electricity generation by source.

consumption is considerably low in the State of Utah. The geological surveys indicating that the region is position thirty-fourth among the American States in issues of power consumption measured through per capita means. Utah consumes approximately 277 million British thermal units (Btu) and the nation's average currently stands at 350 million Btu. In terms of electricity prices, Utah has the 14th lowest average electricity prices in the nation [1]. Figures 2.1 and 2.2 show coal is the main electricity source in Utah and the U.S.

According to the approximated figures from the geological reports, Utah consumes annual coal energy of about 405.5 trillion British thermal units. Such figures make Utah to rank 22nd highest American State in issues concerning the consumption of coal energy [2]. In addition, Utah produced 1.7% of U.S. coal in 2012 and some of that coal was transported through the railroad to destinations like Arizona, California, and Nevada. However, between 2008 and 2013 Utah encountered an electricity generation decrease of 8% due to lower demand from California and Nevada [1]. Natural gas is also another important fuel consumed in the State of Utah. It is the primary heating fuel and it generates 15.65% of Utah's electricity and 27% of the U.S.'s electricity. Nation wise, Utah is ranked 10th in natural gas production [1].

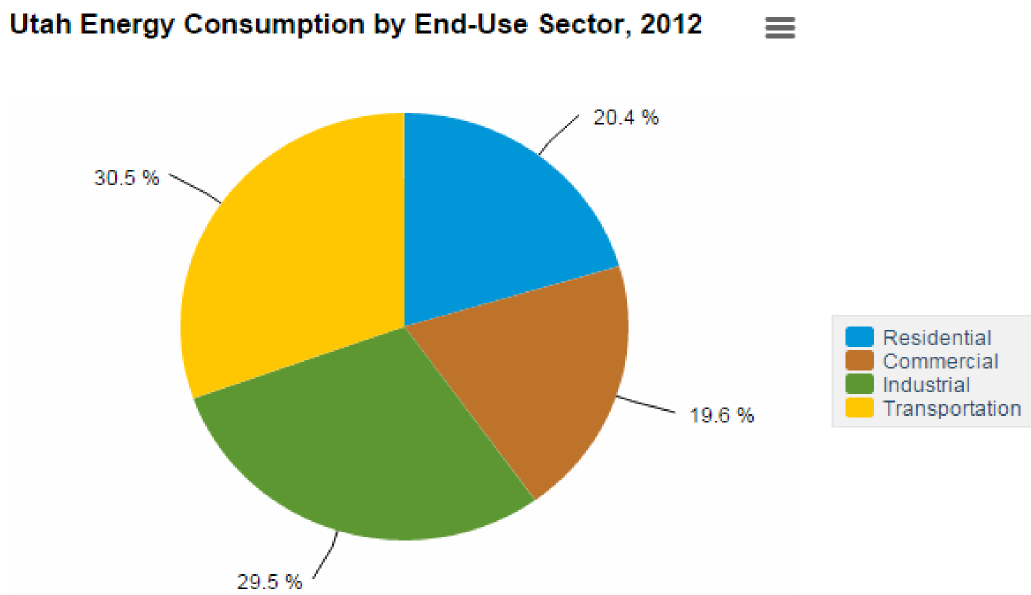


Figure 2.3: Shows Utah energy consumption by End-Use Sector, 2012.

2.1.1.1 Main Areas of Energy Consumption

Power consumption in Utah varies in different sectors, as shown in figure 3. The majority of energy consumption in Utah comes from the transportation sector with a value of 30.5%. The second largest energy consumption sector is industrial by 29.5%, then residential by 20.4%, and finally commercial by 19.6%. The transportation sector has increased about 11% since 1960 [2]. In 2013, the vehicle miles of travel in Utah was about 74 million miles for all vehicle types [3].

2.1.1.2 Energy Imported and Exported

With different mining production, Utah is a net energy supplier. Figure 4 shows the diverse sources of energy produced which include coal, as the most produced source, natural gas, as the second most produced, and finally crude oil. While the U.S. continues to grapple with high oil consumption, the demand for coal is growing worldwide even as the oil reserves continue to diminish [4].

For oil, there are factors of importation and exportation in the energy supply. About 46.6% of the oil consumption in Utah is in the form of gasoline energy, while the rest is in the form of distillate fuels, the liquefied petroleum gases, and the jet fuel. Utah's oil production stands at 230 gallons and about 20% of this energy remains exported to other American States and cities. In fact, the combined efforts of trade and production of energy in Utah is greater than the levels of energy consumption, especially, for coal and natural gas [2].

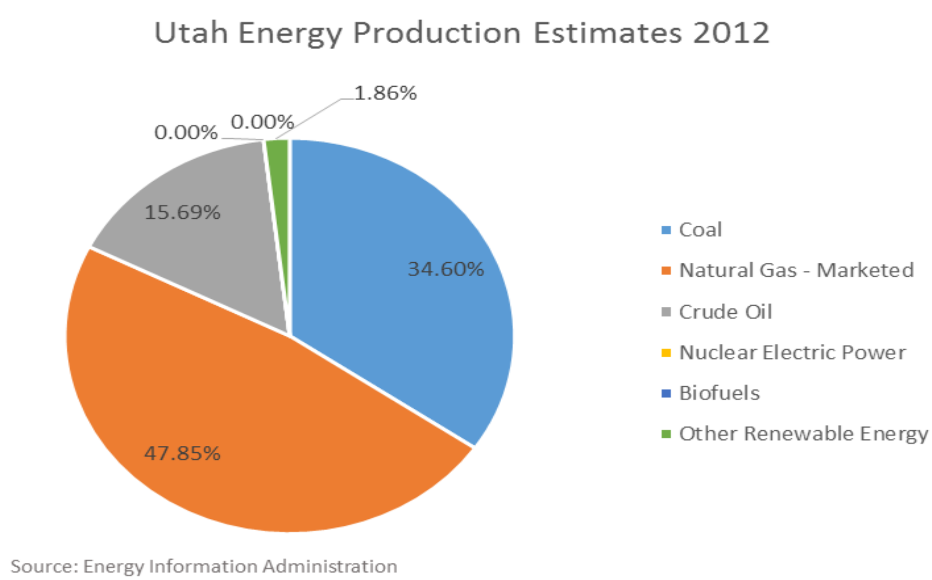


Figure 2.4: Utah's Energy Production by source.

2.1.2 Energy Consumption in Future

The future of energy consumption in Utah and Emery County largely relies on their energy production capabilities and the population growth. Utah is going to see a large growth in demand for energy, as the US Census Bureau noted that there is over a 5% annual population growth in the last couple years and its only expected to increase in the next decade [5]. However, US has had an annual growth rate of just under 1% and the energy consumption per capita has only slightly decreased in the last decade [6]. The efficiency of newly designed technologies is responsible for this decrease in consumption. Higher efficiencies will also impact the future of consumption in the transportation sector. Companies are leaning toward building vehicles with less carbon emissions. The demand for coal has decreased 15% between 1990 and 2012 (see figure 5). In fact, future projections indicate that less electricity will be generated from coal by the year 2040. On the other hand, the demand for natural gas has been gradually rising over the years. In 2040, it is predicted that natural gas will be the most used source for electricity generation. Especially, with the fact that natural gas plants are cheaper to build than coal, or nuclear plants [7]. Finally, nuclear power will account for 16% of 2040 electricity generation.

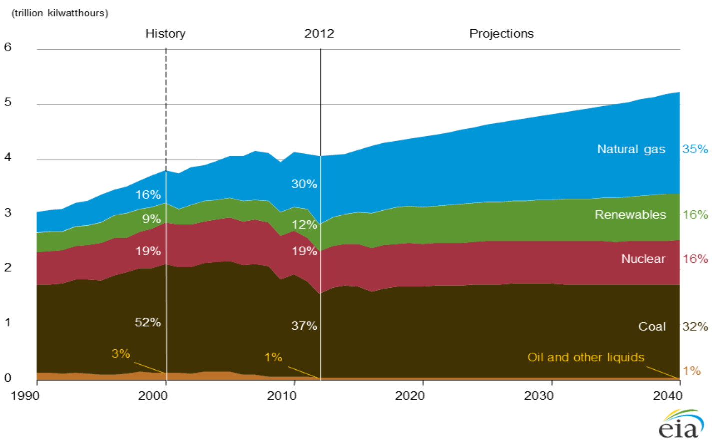


Figure 2.5: Electricity generation by fuel, 1990-2040.

Utah's energy growth is expected to follow the nation's footsteps in terms of the reliance on more natural gas and less coal. Natural gas in Utah is expected to increase 23.7% in the year 2022, while coal is expected to increase 17.9%.

Table 2.1: Projected energy growth for Utah.

Utah's Projected Fossil Fuel Energy Growth – Next 10 years Source: Rocky Mountain Power, Questar, Utah Geological Survey				
	2013	2022	Percent Change	Annual Rate
Electricity Load (RMP) (GWh)	25,153	29,515	17.9%	1.8%
Natural Gas (Questar) (million Dth)	173	214	23.7%	2.4%
Petroleum/Transportation (mbbl/yr)	47	53	12.8%	1.3%

2.2 Analysis of Resources

This section compares the different sources of energy that are currently being used and will be used in the future. These resources include petroleum, natural gas, coal, renewable resources, and nuclear energy. The discussion and comparison of these resources will be focused on the current and future costs of energy production the current supply of each resource and the sustainability and lifespan of each resource. The future cost evaluation will use the levelized cost of energy which includes the cost of the material resource, cost of the infrastructure to produce the energy as well as maintenance cost, transportation cost, and any available government subsidies.

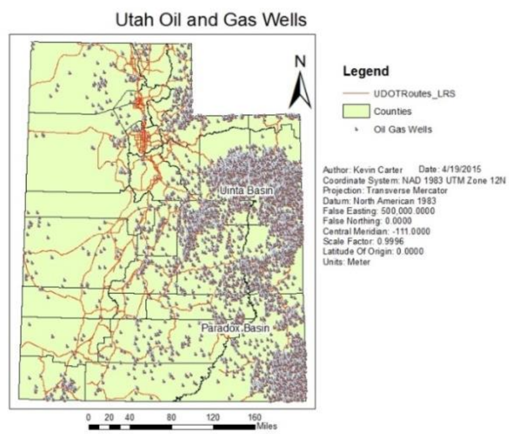


Figure 2.6: Locations of Oil Gas Wells, created in ArcGIS using data from USGS.gov.

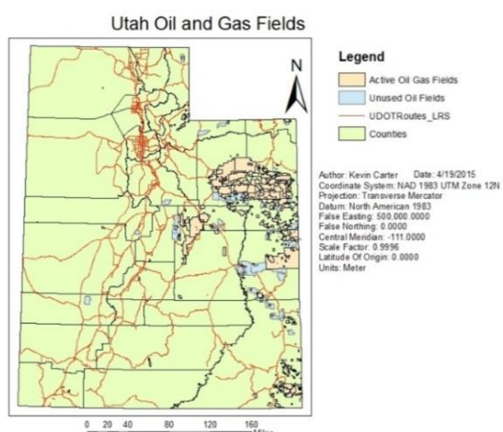


Figure 2.7: Locations of Oil Gas Fields, created in ArcGIS using data from USGS.gov.

2.2.1 Petroleum

One of the largest producers of energy and other byproducts in the world is a substance termed Petroleum. It is described by the American Association of Petroleum Geologists as a “thick, flammable, yellow-to-black mixture of gaseous, liquid, and solid hydrocarbons that occurs naturally beneath the Earth’s surface that can be separated into fractions including natural gas, gasoline, naphtha, kerosene, fuel and lubricating oils, paraffin wax, and asphalt and is used as raw material for a wide variety of derivative products” [8]. The uses for the natural resources encompass a wide range of not only our energy production but extended list of other products; However this section will focus on what the oil industry calls Crude Oil, and how it has affected society in the past and what our future looks like with or possibly without it.

2.2.1.1 Petroleum Supply and Demand

The analysis of the consumption and available supply for crude oil is special to Utah for the reason that it is involved with the extraction,

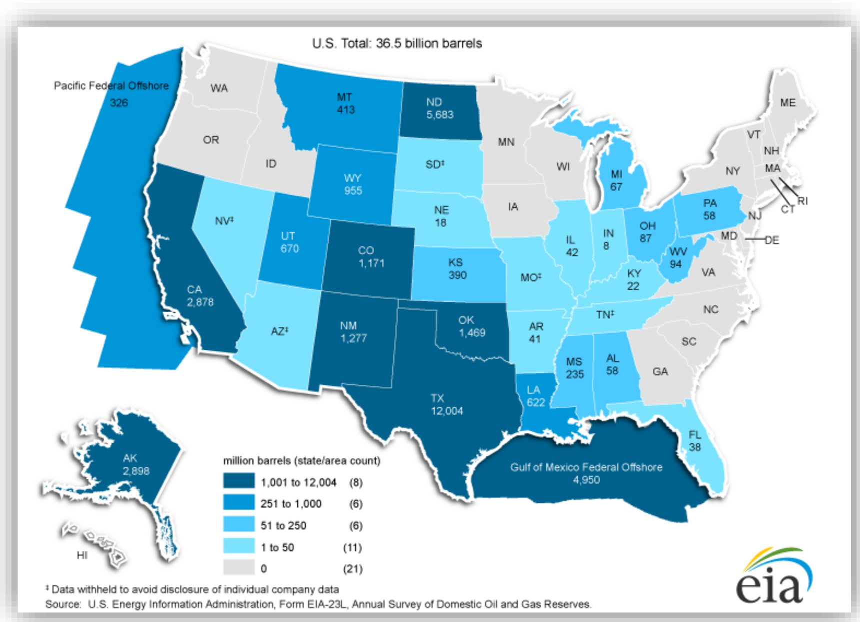


Figure 2.8: States Estimated Proven Reserves of Petroleum by EIA.

refinement, and distribution processes. Crude Oil drilling operations and wells are concentrated mostly in the Uinta Basin and Paradox Basins as seen in Figure 2.6 and Figure 2.7 shows the location of known oil fields in the Uinta Basin area as well. The United States Energy Information Administration records all energy related information on their website for the entire country as well as individual states. According to the US EIA website in 2013, Utah has approximately 613 million barrels of oil reserves within its borders which is equivalent to 1.8% of the total US share of Oil [1]. So while Utah does have some crude oil, it represents a small portion of United States as a whole. For comparison, Canada has approximately 180 billion barrels of crude oil reserves which is slightly under six times the US reserve. Figure 2.8 shows a map of each state with its estimated petroleum reserve.

Utah has a unique geographic situation that has states to the North West with no Oil reserves and has areas to the North and East with large Oil reserves. Salt Lake City has taken advantage of this by importing crude oil via the Frontier Pipeline and Pioneer Pipeline from Canada, Wyoming, Colorado and Utah to its 5 large refineries. The refineries produce motor gasoline, diesel fuel, jet fuel, other fuel oils, and wax. The total production from them is 3.609 million barrels a year, representing more than one-fourth of the refining capacity in Petroleum Administration for Defense District (PADD) 4 and 1.3% share of the total United States production [1]. Low production cost in Utah in combination with the Chevron Pipeline allows the refineries to transport and sell much of its refined oil to Washington, Idaho, Oregon, and Nevada. This contributes a very large amount to the State’s largest source of income, which is the Energy Export sector.

Both in and out of State there is a decent amount of oil for the State the currently meets the demand from the market; However because of the large exportation of petroleum products, the sustainability of this industry depends on finding new reserves and increasing efficiencies in production and consumption. In addition Utah's new energy plan wants the state to become self-reliant on its own energy reserves. According to the plan with current known reserves and production rates, if Utah were to use only its own oil it would be depleted in 26 years [9]. While this does not include undiscovered reserves or more efficient production and consumption, it is important to highlight that the petroleum industry for the future is relatively dependent on outside sources currently.

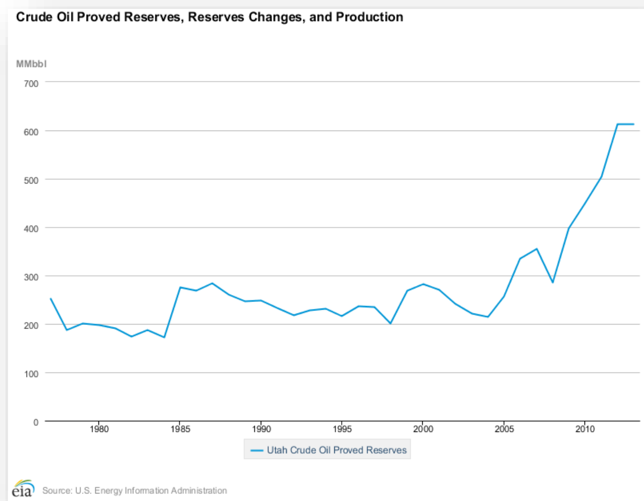


Figure 2.9: Proven Reserves of Crude Oil by EIA.

For the same reason however it must be determined if being self-reliant on energy is necessary.

2.2.1.2 The Future of Petroleum in Utah

Crude Oil is a non-renewable resource which means that the supply is fixed even though the demand is increasing exponentially. New reserves will need to be found and managed at a rate to keep up with the consumption. The demand for petroleum products in Utah's future will then depend on this as well as a number of other factors. The key factors in what is the projected use of oil depends on rate of economic growth and the both the price and amount of the resource [10]. Figure 4 does show promise with; however in that exploration and technological advances in the last 40 percent has increased the known reserves amount in Utah by over three hundred percent.

This large increase seen is directly related to hydraulic fracturing advances in the last 5 years. Large quantities of oil or gas have been found in tight sands, shale's and coalbed formations; however these formations have a poor flow rate due to low permeability or from clogging of the formation during drilling [11]. Since they are difficult to extract based on the formations around them, normal drill rigs for petroleum cannot extract them. Hydraulic fracturing then stimulates wells drilled into these formations injecting fracturing fluid into the well at high pressures until the pressure created causes the formation to crack or fracture. Once the fractures have been created, the oil begins to flow back to the surface, making profitable otherwise prohibitively expensive extraction [11]. This is currently being performed across the country as well as in Utah with large returns because of the vast amount of crude oil being found.

With this information in mind, substitutes like hydraulic fracturing are important to consider because they are extending the time frame we can use these nonrenewable resources. Another alternative natural resources found in Utah currently being studied are Tar Sands. This resource is mined and processed to generate oil similar to oil pumped from conventional oil wells, except extracting oil from tar sands is more complex than conventional oil recovery. Oil sands recovery processes include extraction and separation systems to separate the bitumen from the clay, sand, and water that make up the tar sands. Bitumen also requires additional upgrading before it can be refined. Because it is so viscous it also requires dilution with lighter hydrocarbons to make it transportable by pipelines [12]. This is an important subject for Utah's energy discussion because it has some of the largest deposits of the mineral in the world. The main issue however is that current methods for extracting the oil is expensive and extremely environmentally degrading.

Other substitutes include several non-oil-based alternate fuels. These include bio fuels like ethanol and biodiesel. Bio fuels are created most often from corn, sugar cane, vegetable oil, and other oils [9]. Because of their agricultural origins, the production of this fuel source affects competition for traditional uses of corn and sugar cane as food ultimately leading to a rise in food prices. Natural Gas is another alternative to petroleum and is discussed further in the next section.

2.2.2 Natural Gas

Natural gas is a fossil fuel formed when layers of buried plants and animals are exposed to intense heat and pressure over thousands of years. The energy that the plants and animals originally obtained from the sun is stored in the form of carbon in natural gas. Wells are drilled into the ground to remove the natural gas. After the natural gas is extracted, it is treated at gas plants to remove impurities such as hydrogen sulfide, helium, carbon dioxide, hydrocarbons, and moisture. Pipelines then transport the natural gas from the gas plants to power plants and to homes for heating [13]. Since it is naturally occurring on the planet over an extended period it is a nonrenewable resource. In Utah, natural gas is used primarily for heating buildings but it is also used for generating electricity and commercial transportation.

2.2.2.1 Natural Gas Supply and Consumption

There are two major natural gas fields in the state which are located in the Uinta Basin area; in 2013, Utah as a whole produced 470,863 million cubic feet of natural gas, approximately 1.8% of total U.S. production [1]. In relation to Petroleum it is very similar in percentage to the US market share. In 2013, the Energy Information Administration also reported Utah reserves totaled 6.829 billion cubic feet of natural gas, making up 2.0% of all reserves in the country. This has seen a variable increase in the last few decades as seen in Figure 2.10.

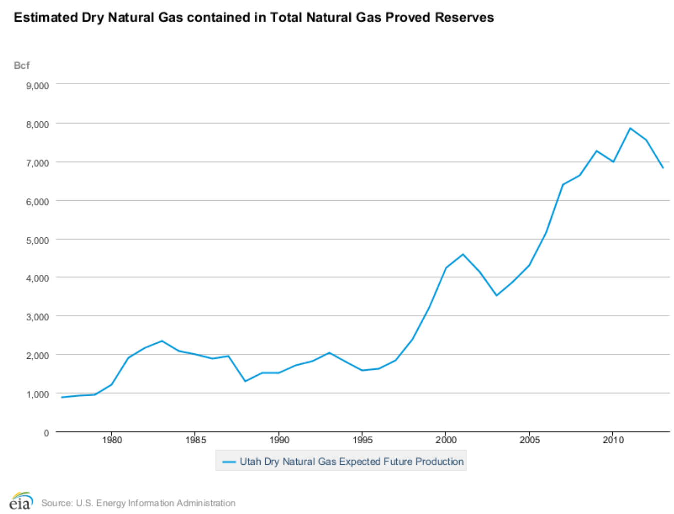


Figure 2.10: Proven Reserves of Natural Gas by EIA.

Natural gas has become a very important resource to Utah in the last few decades. From 1980 and 2013, Utah natural gas reserves and production grew by over seven hundred percent due to the exploitation of existing reserves and the discovery of new reserves. A newer notable natural gas resource comes from Coalbed methane. According to the EIA it is natural gas produced from coal seams and has provided almost one-third of Utah's natural gas output but has been gradually declining from its 2002 peak [1].

Natural gas is another export for Utah because the states usage is equivalent to only about half of the natural gas it produces. The residential sector is the primary consumer with six in seven homes using natural gas as their primary heating fuel [1]. Compressed natural gas is also a growing demand for the transportation sector in the state. It is primarily used for commercially operated vehicles but Utah has a growing number of public refueling stations for vehicles using compressed natural gas (CNG). And in 2014, EIA reported Utah with the fourth largest number of public access CNG refueling stations in the country [1]. Figure 2.11 shows the distribution of Natural Gas usage by sector.

Utah's gas pipeline infrastructure allows substantial volumes of natural gas to be imported and exported from Utah. These pipelines include both the Questar Pipeline and the Kern River Gas Transmission Pipeline [1]. With this infrastructure established and in addition relatively low extraction costs, natural gas is another large contributor to the energy royalties that Utah enjoys.

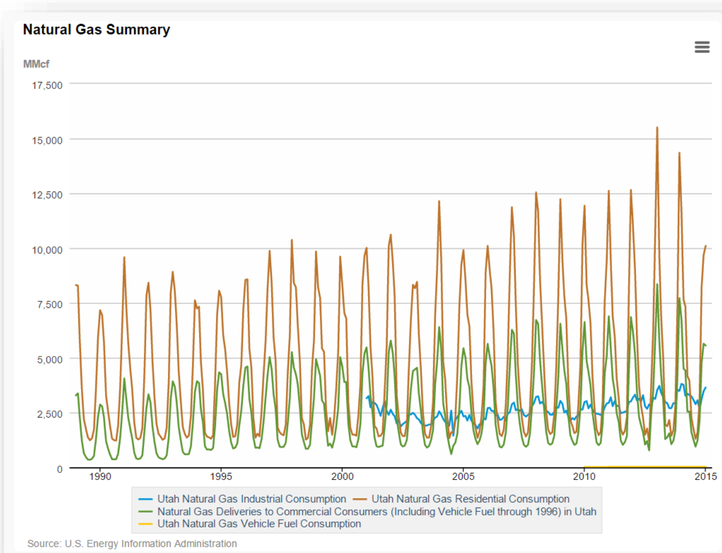


Figure 2.11: Natural Gas Usage by Sector from EIA.

2.2.2.2 The Future of Natural Gas in Utah

The abundant gas supply in the Rocky Mountain region helps keep prices for Utah consumers lower than almost any other area of the country. And compared to other non-renewable resources, natural gas is a very clean source of energy, with minimal environmental and health effects [13]. Demand for natural gas is expected to increase so new reserves of natural gas will need to be explored. According to the Governors Strategic Plan with current known resources and consumption rates, if Utah was self-reliant on its own Natural Gas we would drain our supplies in 18 years [9]. Although self-reliance is not a need for the state and instead just a goal set by the political leaders this is not as big of a concern as it is a consideration.

2.2.3 Coal

Coal is a fossil fuel formed from the decomposition of organic materials that have been subjected to geologic heat and pressure over millions of years. Coal is a nonrenewable resource for the reason it cannot be replenished on a human time frame. The mineral is extracted from surface or underground mines and then cleaned at the coal mine to remove impurities before it is transported to the power plant. At the power plant, coal is commonly burned in a boiler to produce steam which runs through a turbine to generate electricity [14]. It is the largest producer of energy for Utah presently which as shown in Figure 2.12.

2.2.3.1 Coal Production and Supply

In Utah, coal is used to generate 80.7% of all electricity and uses about 75% of Utah’s annual coal production [1]. Across the border in Wyoming is the largest coal producer in the country, which produces over 70% of the Western US’s coal production. Much of this coal is transported to Utah’s coal power plants by rail and truck. Utah also has its own coal mines that are located in the Wasatch Plateau, Book Cliffs, and Emery coal fields. These mines in Utah have known reserves from producing mines of approximately 157 million short tons, equivalent to 0.8% of the total share of United States coals, which has over 25% of the world's supply of coal [1]. This is greater than the remaining reserves of both natural gas and oil; but not all of this coal is accessible because of things like land use, property rights, physical environment, and the recovery

Table 2. Ten Largest Plants by Generating Capacity, 2010

Plant	Primary Energy Source or Technology	Operating Company	Net Summer Capacity (MW)
Utah			
1. Intermountain Power Project	Coal	Los Angeles City of	1,800
2. Hunter	Coal	PacifiCorp	1,336
3. Huntington	Coal	PacifiCorp	911
4. Lake Side Power Plant	Gas	PacifiCorp	557
5. Currant Creek	Gas	PacifiCorp	540
6. Bonanza	Coal	Deseret Generation & Tran Coop	458
7. Gadsby	Gas	PacifiCorp	348
8. KUCC	Coal	Kennecott Utah Copper Corporation	213
9. Milford Wind Corridor I LLC	Other Renewables	Milford Wind Corridor Phase I LLC	204
10. West Valley Generation Project	Gas	CER Generation LLC	189

MW = Megawatt.
Source: U.S. Energy Information Administration, Form EIA-860, "Annual Electric Generator Report."

Figure 2.12: The Largest Energy Generation for Utah by EIA.

rates by type of mining affect the ability to obtain coal. In addition there is an estimated 14 billion short tons reserve supply of coal in Utah that has not been tapped [1].

According to the EIA data, production of coal used to produce a large majority of the state's energy is stated as 16,977 thousand short tons per year [1]. At that rate Utah could be dependent on it's on coal for approximately 10 years from already producing mines; however since a majority of the coal is imported from Colorado and Wyoming where their reserves are far greater that supply time frame is closer to 100 years' worth of supply from producing mines to the 34 States that energy is exported [1].

Based on the listed information coal is cheap and very steady supply energy for Utah and the country to use. The largest downside however is the environmental impacts caused directly from coal production which include air emissions, water resource use, and solid waste by products. When coal is burned, 2249 lbs/MWh of carbon dioxide, 13 lbs/MWh of sulfur dioxide, 6 lb/MWh of nitrogen oxides, as well as mercury compounds are released [14]. These elements expose serious threats to a variety of life forms when consumed in large amounts according to the EPA. The other main issue with coal mining and energy production is the water use where it uses large amounts to remove impurities in mining, and even more is used at the coal power plant to produce steam and to cool the system. In addition pollutants build up in the water supply at the power plant which are then released into the atmosphere as steam and back into the lakes and rivers in which the water is extracted from [14]. Although coal is very effective energy source for the state and country, many revisions are needed to make both more efficient and environmentally friendly.

2.2.3.2 The Future of Coal in Utah

The future of coal in the world is surrounded by the idea of clean coal. Current research has found alternative ways to produce energy from coal with cleaner electricity as the main motive. Some of these are brand new and other have been in place for many year. Here is a list of notable changes:

- Coal cleaning by 'washing' has been standard practice in developed countries for some time. It reduces emissions of ash and sulfur dioxide when the coal is burned [15].

- Electrostatic precipitators and fabric filters can remove 99% of the fly ash from the flue gases – these technologies are in widespread use [15].
- Flue gas desulfurization reduces the output of sulfur dioxide to the atmosphere by up to 97%, the task depending on the level of sulfur in the coal and the extent of the reduction. It is widely used where needed in developed countries [15].
- Low-NOx burners allow coal-fired plants to reduce nitrogen oxide emissions by up to 40%. Coupled with re-burning techniques NOx can be reduced 70% and selective catalytic reduction can clean up 90% of NOx emissions [15].
- Increased efficiency of plant – up to 46% thermal efficiency now (and 50% expected in future) means that newer plants create less emissions per kWh than older ones [15].
- Advanced technologies such as Integrated Gasification Combined Cycle (IGCC) and Pressurized Fluidized Bed Combustion (PFBC) enable higher thermal efficiencies still – up to 50% in the future [15].
- Ultra-clean coal (UCC) from new processing technologies which reduce ash below 0.25% and sulfur to very low levels mean that pulverized coal might be used as fuel for very large marine engines, in place of heavy fuel oil. There are at least two UCC technologies under development. Wastes from UCC are likely to be a problem [15].
- Gasification, including underground coal gasification (UCG) in situ, uses steam and oxygen to turn the coal into carbon monoxide and hydrogen [15].
- Sequestration refers to disposal of liquid carbon dioxide, once captured, into deep geological strata [15].

The downside to a majority of these technologies is the increase in operating costs and the decrease in efficiency in production; however with recent taxes on carbon emitter increasing this can become less of an excess cost in the future. Currently in 2015 a large amount of coal power plants are reaching retirement and will needing decommission and replacement. According to the Annual Energy Outlook for 2015, 120 coal plant projects are in the construction, permit, or project design phases and are expected to be completed over the next two decades [10]. These coal power plants will be equipped with all the most recent technologies creating much cleaner coal energy. One issue with this plan is asking if there is an alternative to these plants before they are built. When comparing the cost of building a new coal power plant with other types of electrical generating plants, such as nuclear or natural gas plants, coal plants cost less to build [9]. Estimates to build a new clean coal power plant put costs at $1.5 billion and four years of construction.

Comparatively, new construction of a nuclear power plant can cost over $2 billion and can take five years to complete [6]. This is only a comparison of the initial costs and does not consider the production costs of these plants.

2.2.4 Renewable Energy

According to the United States Energy Information Administration 13.3% of the total electricity generated in the United States for the month of January 2015 was classified as renewable energy. Of this 13.3%, 6.8% was produced at hydroelectric plants [1]. There are many sources of renewable that are currently being used to provide energy in different parts of the world. Renewable energy is energy that is generated by sources that will not be depleted. There is an endless supply of energy from renewable energy sources, which creates a great importance for the use of this form of energy. The most common forms of renewable energy that are in use today are hydroelectric, wind, solar, and geothermal. The majority of energy that is produced today is produced from the use of fossil fuels and other sources that will one day run out. The greatest advantage of using renewable energy sources is that the supply will never run out. The downside of renewable energy sources is that they are not reliable. The use of these sources is dependent on nature and the changes in nature to make the use of renewable energy sources not possible all of the time.

2.2.4.1 Renewable Energy Sources

The most used source of renewable energy is water through hydroelectric energy generation. The majority of the planet is covered with water, which creates many opportunities to take advantage and create energy from water. Hydroelectric power makes up just over half of the total energy that is produced in the United States that is classified as renewable energy. The most common way to obtain energy from water is through hydroelectric power plants. This process takes place where there is a reservoir of water that can be used to run the plant. The majority of these plants are located on a river that has been dammed to create a large reservoir of water. Water is release from the reservoir at a desired rate in order to run the hydroelectric plant. Water that falls due to the force of gravity is used to run a turbine that rotates and creates power through a generator. The greatest risk to the use of hydroelectric power plants is drought. For example, the current drought in the state of California has left the water reservoir at such a low level that water is not being released at the usual rate creating a decrease in the power generated. When water levels are low the capacity to produce energy decrease and at times ceases.

The next largest source of renewable energy being produced in the United States is wind. Energy is produced from wind much like the way hydroelectric plants are run. Wind currents are used to rotate a turbine, which then produces energy in a generator. Wind is an excellent source of energy for the future due to the clean way that it is produced. Wind energy does not produce any pollution or any type of waste that has to be disposed of. The drawback of the use of wind energy is the unreliable nature of wind currents. There are areas that have greater amounts wind and stronger wind currents but even in these locations wind is not reliable therefore the amount of energy that can be produced is not reliable. Geothermal energy and solar energy are the other significant sources of renewable energy in the United States. Geothermal uses heat from within the earth to produce energy. Using sunlight and solar cells to create energy creates solar energy.

2.2.4.2 Cost of Renewable Energy

The United States Energy Information Administration has predicted the levelized cost of electricity for all of the significant sources of energy in the United States for the year 2019. There is a very wide range of levelized costs for renewable energy in the future depending on the source of the renewable energy. Geothermal energy has the lowest predicted levelized cost of energy with a predicted cost of 44.5 $/MWh. Factored into this prediction is a government subsidy of 3.4 $/GWh. Wind and hydroelectric energy has a 2019 predicted levelized cost of energy similar to many nonrenewable energy sources. The levelized costs of wind energy and hydroelectric energy are, 80.3 $/GWh and 84.5 $/GWh respectively [7].

2.2.4.3 Renewable Energy in Utah

Utah is far below the average of the rest of the United States when it comes to the percentage of total energy produced being from renewable sources. According the United States Energy Information Administration, for the month of January 2015 Utah produced 3.7% of its total energy from renewable sources compared to 13.3% for the rest of the country. Of the 3.7% produced in Utah 1.4% was from hydroelectric facilities while the remaining 2.3% came from other renewable sources [1]. There are many opportunities to use renewable energy in the state of Utah. Throughout the state of Utah, there are sites that are capable of creating energy from renewable sources. Shown below, figure 2.13, is a map of Utah showing the location of sites that have the capacity to produce renewable energy. For the goal of Utah become self-sustainable in the production of energy, the renewable energy sources in Utah need to be further investigated and used.

2.2.5 Nuclear Energy

Nuclear energy is the most controversial form of energy currently being used in the United States and in the world. This is due to the high risk that is involved in the case of a catastrophe. The process of producing nuclear energy as well as the risks involved will be covered in depth in later sections. A significant amount of the energy of the United States is produced in nuclear power plants. According to the United States Energy Information Administration, 20.6% of the total energy produced in the United States in the January of 2015 was produced in nuclear power plants [1]. This was the third largest source of energy only being surpassed by coal and natural gas. As a general trend, the amount of nuclear energy produced in the United States greatly increased from about 1970 until around the turn of the century. At this point the nuclear energy production has leveled off and held steady. These trends are shown in Figure 2.14.

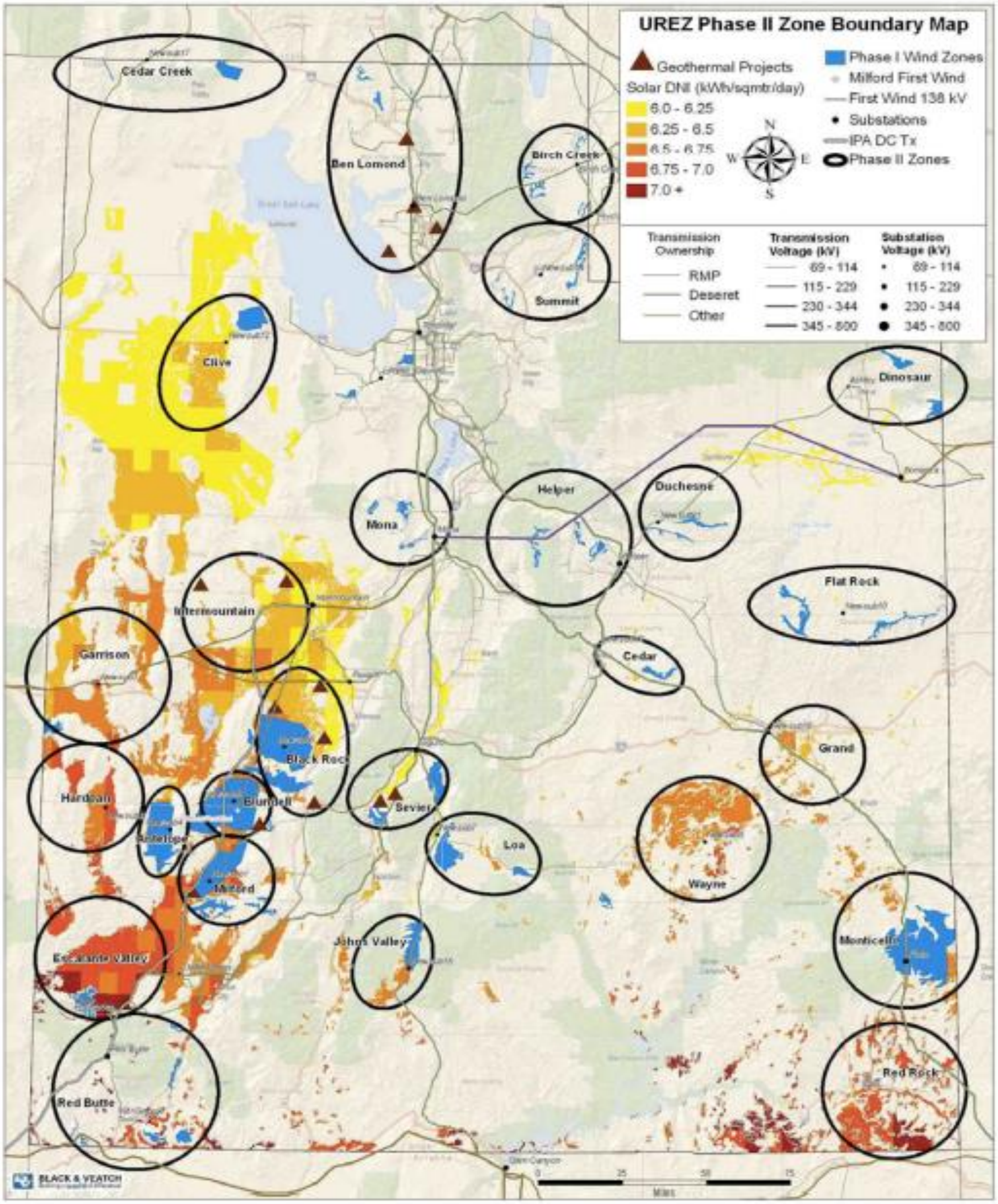


Figure 2.13: Source Black & Veatch Corporation.

2.2.5.1 Cost of Nuclear Energy

The levelized cost of nuclear energy as predicted by the United States Energy Information Administration will be used to discuss the cost of nuclear energy. Major factors that greatly influence the cost of nuclear energy include; changing cost of uranium, storage and transportation of nuclear waste, and government subsidy. For 2019 the United States Energy Information Administration predicts a levelized cost of nuclear energy of 86.1 $/MWh. This levelized cost includes a government subsidy of 10 $/GWh [7]. This prediction puts the cost of nuclear energy right in the range of the cost of other sources of energy. Figure 2.15 shown below shows the levelized cost of nuclear energy as well as that of other the other major sources.

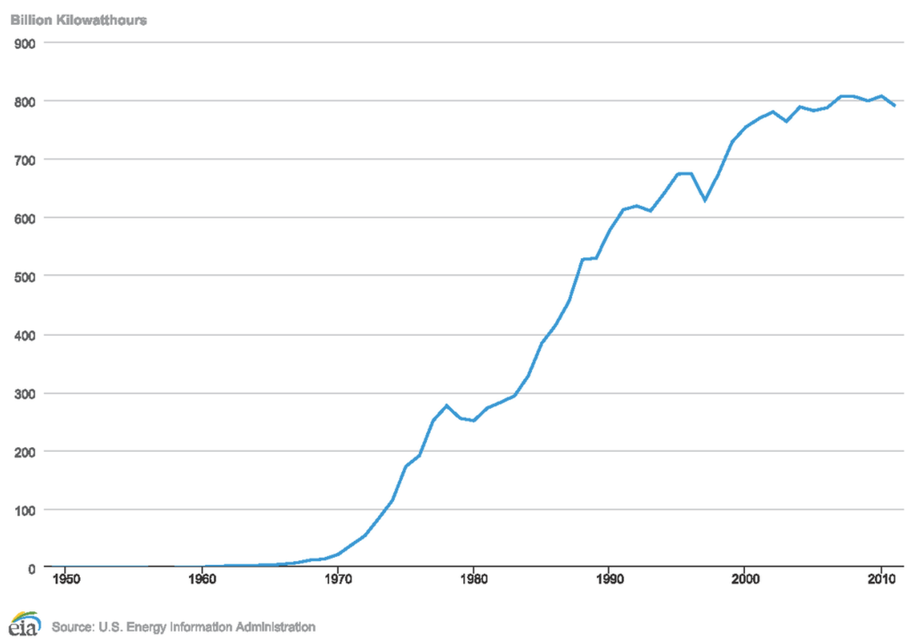


Figure 2.14: Electricity Net Generation: Total (All Sectors), 1949-2011, Nuclear Electric Power.

2.3 References

[1] US Energy Information Administration, "Utah State Energy Profile," US EIA, 21 August 2014. [Online]. Available: http://www.eia.gov/state/print.cfm?sid=UT. [Accessed April 2015].

[2] Matsumor, "Utah’s Energy Use & Resources," Utah Foundation, Salt Lake City, 2008.

[3] UDOT, "2013 Vehicle Miles of Travel by County by Ownership," UDOT, 2014. [Online]. Available: http://www.udot.utah.gov/main/uconowner.gf?n=15059124033524290. [Accessed 28 April 2015].

[4] C. Gleich, "Utah's Energy Issues and Implications doe Public Policy," Hinkley Journal of Politics, vol. 1, no. 1, pp. 7-14, 2011.

[5] US Census Bureau, "State & County Quickfacts," US Census Bureau, 31 March 2015. [Online]. Available: http://quickfacts.census.gov/qfd/states/49000.html. [Accessed 5 April 2015].

[6] IAEA, "Country Nuclear Power Profiles: United States of America," 2014. [Online]. Available: https://cnpp.iaea.org/countryprofiles/UnitedStatesofAmerica/UnitedStatesofAmerica.h tm.[Accessed 2015 4 April].

[7] EIA.gov, "EIA-Annual Energy Outlook 2014 Early Release," EIA, 2013. [Online]. Available: http://www.eia.gov/forecasts/aeo/er/early_elecgen.cfm. [Accessed 28 April 2015].

[8] American Association of Petroleum Geologists, "Petroleum Through Time," American Association of Petroleum Geologists, 2015. [Online]. Available: http://www.aapg.org/about/petroleum-geology/petroleum-through-time/what-is-petroleum. [Accessed April 2015].

[9] A. Smith, "Energy Initiatives and Imperatives: Utah's 10 Year Strategfic Energy Plan," Governor's Office, Salt Lake City, 2011.

[10] John J. Conti, "Annual Energy Outlook 2015," U.S. Energy Information Administration, Washington DC, 2015.

[11] Earthworks, "Hydraulic Fracturing 101," Earthworks, [Online]. Available: http://www.earthworksaction.org/issues/detail/hydraulic_fracturing_101#.VTXFvCG4R D8.Accessed April 2015].

[12] US Oil Sands Inc, "Utah's Oil Sands," 2015. [Online]. Available: http://www.usoilsandsinc.com/index.php?page=utahs_oil_sands. [Accessed 26 January 2015].

[13] US Environmental Protection Agency, "Natural Gas," US Environmental Protection Agency, 25 9 2013. [Online]. Available: http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html. [Accessed 18 4 2015].

[14] US Enviromental Protection Agency, "Coal," US Enviromental Protection Agency, 25 9 2013. [Online]. Available: http://www.epa.gov/cleanenergy/energy-and-you/affect/coal.html. [Accessed 18 4 2015].

[15] World Nuclear Association, "'Clean Coal' Technologies, Carbon Capture & Sequestration," World Nuclear Association, Feb 2015. [Online]. Available: http://www.world-nuclear.org/info/Energy-and-Environment/-Clean-Coal--Technologies/. [Accessed 20 April 2015].

Chapter 3

AP1000 Reactor System: Details and Specifications

Abstract

The reactor type chosen for the Blue Castle Project is the AP1000 which is a third generation Pressurized Water Reactor (PWR) manufactured by Westinghouse's nuclear division. The essential components and technical specifications of the AP1000, such as the reactor core, the pressurizer in the first coolant loop and the turbine and condenser of the second coolant loop will all be described at length. In addition to discussing the technical specifications of the AP1000 and its safety systems, this chapter will discuss in a general sense how nuclear reactors work, the AP1000's improvements over previous generations of PWRs and a brief comparison of how a PWR differs from other reactor types.

3.1 Introduction

Blue Castle plans to employ two Westinghouse AP1000 Nuclear Reactors within its nuclear power plant proposed to be constructed in Green River, UT [1]. The AP1000 is a third generation pressurized water reactor (PWR) [2]. This chapter details the AP1000 and explores the features that differentiate this reactor from other designs. This chapter also investigates the safety and cooling systems of the reactor and estimates net water usage requirements of the proposed plant based on reactor specifications. Finally, the chapter closes with detailed technical specifications for the AP1000. Power production is estimated based upon theoretical and empirical data provided by Westinghouse and the NRC.

3.2 The reactor at Blue Castle

The reactor type chosen for the Blue Castle Project (BCP) is an AP1000 pressurized water reactor built by Westinghouse. The AP1000 is a pressurized light water reactor that operates at a pressure of 2250 psi and uses enriched uranium as the fissile fuel source. According to Westinghouse, the AP1000 contains 75% less piping, 60% fewer valves, 80% less control cable, 35% fewer pumps and 50% less building volume than similar output PWR's. The power output of an AP1000 is 1117 MWe, meaning it has a theoretical peak power production of 1117 megawatts of electrical power [3].

3.3 How a reactor works

All nuclear reactors work by using the reactor core to heat water to turn water into steam to spin a turbine that is connected to a generator that produces electrical current. Inside the reactor core is a series of uranium rods that sustain a fission reaction. A fission reaction occurs when the nucleus of one atom contacts another and is split into smaller parts during the radioactive decay process. This splitting releases a very large amount of energy.

This energy comes in several forms: kinetic energy, gamma rays and radioactive decay. The kinetic energy of fission reactions is converted to thermal energy when the nucleus of a split atom collides with another atom. Gamma rays, a form of radioactive particle, also produce heat during the reaction. Radioactive decay produces heat on its own, this decay heat source remains even after the reactor is shut down and the fuel is removed. Each fuel rod consists of a series of enriched uranium dioxide pellets that are enchased in a ZIRLO tube, which is a zirconium alloy that remains stable and does not corrode when submerged in water or when it is subjected to a nuclear reaction [4]. These fuel rods are arrayed in a 17 rod x 17 rod square array. Between each of these rods is a control rod. A typical arrangement of fuel and control rods is shown in Figure 3.1.

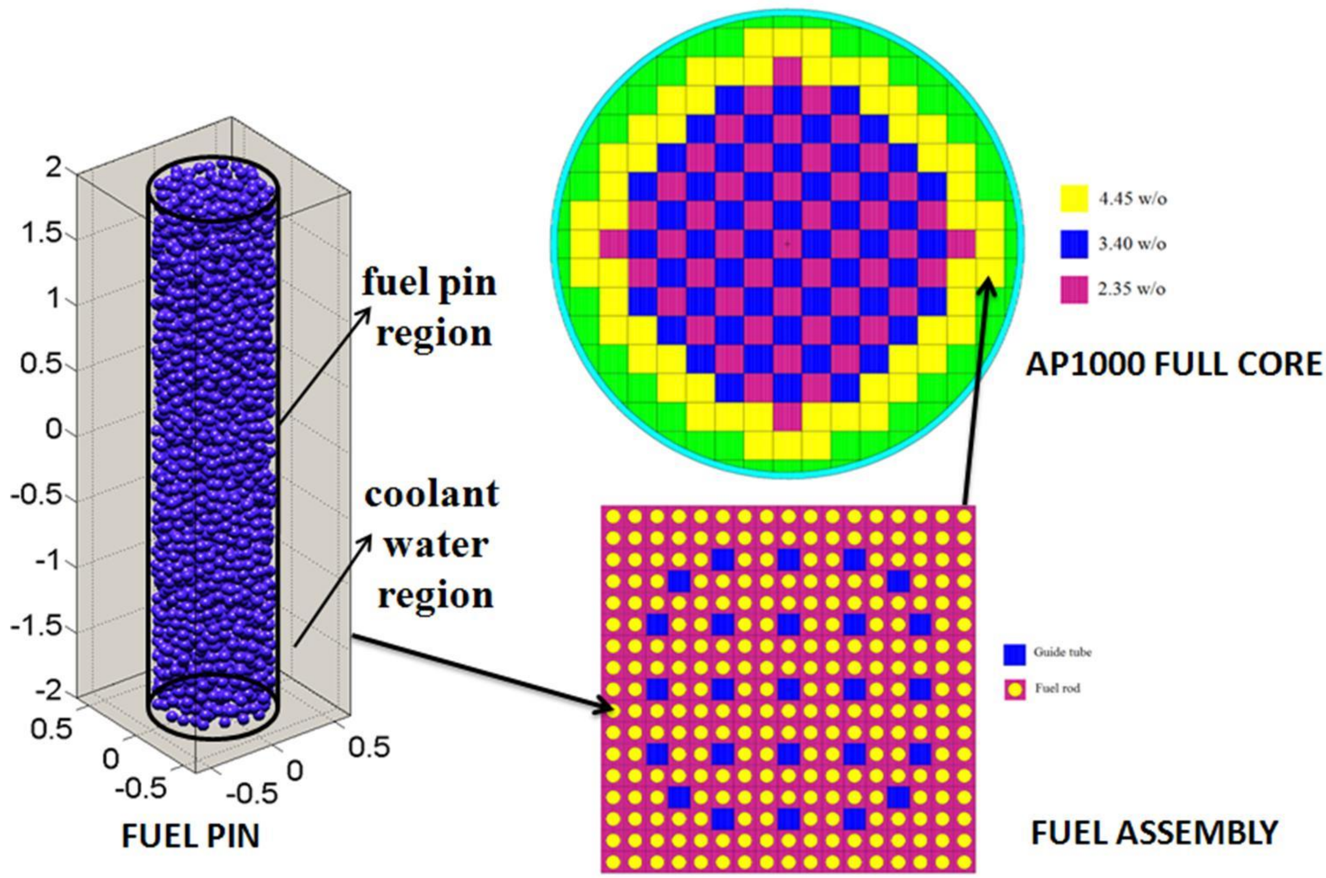


Figure 3.1: Reactor Array [5].

Control rods adjust the relative power output of a reactor by allowing more or less fissions to occur, analogous to the way a gas pedal allows more or less fuel and air into a car's engine to control power output. In the case of the control rods, since they block the reaction when inserted into the reactor, pulling them out allows the system to produce more fission occurrences which in turn generates more heat which translates to more steam to turn the turbines. The control rod functions by absorbing traveling fissile elements. Unlike when a fissile element contacts an atom in a fuel rod where the contacted atom splits, contact with a control rod does not result in a fission split due to the control rod being made of a material that does not allow a fission reaction to occur [6]. In the case of the AP1000, the control rods are made of boron [7]. Control rods only have a finite lifespan and need to be replaced periodically. The control rod lifespan is variable and dependent on usage. Figure 3.2 shows typical fuel rod actuation within a reactor core.

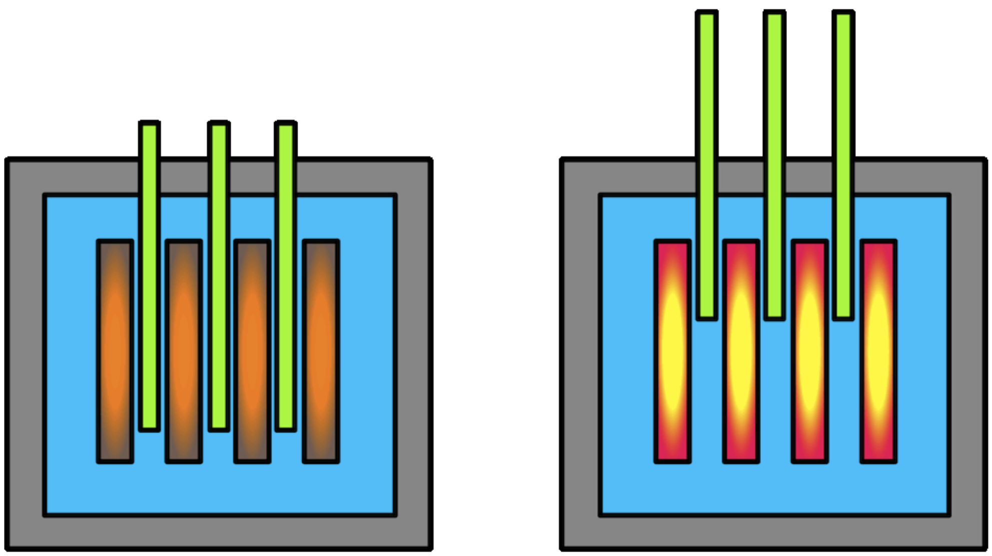


Figure 3.2: Control rod representative diagram [6].
Left: inserted control rods, retarded fission reaction.
Right: normal operating position of the control rods.

All of this heat is collected by the moderating materials. In the case of the AP1000, light water is used. Light water is what the nuclear industry calls normal water, instead of heavy water whose hydrogen atoms contain a neutron. The pressurized portion of the pressurized water reactor is inside the reactor itself. The coolant water around the core is pressurized to 2250 psi so that it can transfer heat at a higher temperature than the normal boiling point of water without actually causing the water to boil. This water is also radioactive so it is only used within the reactor itself in a closed loop. Because of this radioactivity, the water is pumped into what is known as a steam generator, which is basically heat exchanger. A heat exchanger is a vessel which interfaces the hot water from the one source and the cooler water of another source analogous to the radiator of a car, but rather than transferring heat from water to air it transfers from primary coolant loop water to secondary coolant loop water. The heat is transferred from the radioactive moderating agent into the second coolant loop water within the steam generator by pumping the radioactive moderating agent through a series of pipes within the steam generator vessel. On the outside of those pipes but still within the steam generator is the water of the steam loop. This steam is then pumped through to the steam turbine, which is similar in effect to a wind turbine only it uses pressurized steam to turn the blades instead of wind power. Heating the water to steam instead of allowing it to boil allows for a significantly higher Carnot efficiency and thus much greater energy transfer to the turbines. The steam is then cooled inside a condenser and allowed to return to its non-pressurized liquid phase and then pumped back into the steam generator where any remaining heat is recycled. The water pumped through the condenser is flashed to steam by the heat of the secondary coolant loop and vents to atmosphere via the cooling tower which creates the distinctive white clouds commonly associated with nuclear power plants.

The rotational energy from the steam turbine is used to turn an overdrive gearbox which allows the output shaft to spin significantly faster than the input shaft. The output shaft is attached to an electric generator which in turn produces the electricity. This electricity is then sent out over transmission lines for use.

3.4 Overview and Comparison with Other Reactor Types

The Pressurized water reactor (PWR) is the most common nuclear reactor type employed within nuclear power plants [23]. The United States currently operates just two types of nuclear reactors: pressurized and boiling water reactors. The PWR is one of three light water reactor types and light water is one of many classes of nuclear power plant reactor types [23]. PWRs are preferred for their relatively high stability and compact design. This section defines what differentiates a PWR from the other major nuclear reactor types and provides a comparison detailing the similarities and differences between the PWR and other designs. This section also contains advantages and disadvantages of the PWR relative to the other designs.

3.4.1 What Makes a Pressurized Water Reactor?

The defining characteristic of the PWR is the configuration of the cooling system. Other defining characteristics are largely a function of the coolant system configuration. In a PWR, two coolant loops are joined in series by a heat exchanger. The two loops are closed, while a third loop joined to the secondary loop via a condenser remains open and vents steam via the cooling tower. This configuration ensures that the radioactive material within the core remains isolated and does not transfer to the secondary or tertiary loop and ultimately the outside environment. The term 'pressurized' refers to the primary coolant loop which comes into direct contact with the radioactive material. The primary loop is pressurized to maintain a single phase (liquid) which reserves steam generation for the primary heat exchanger. Figure 3.3 illustrates a typical cooling system configuration for a PWR.

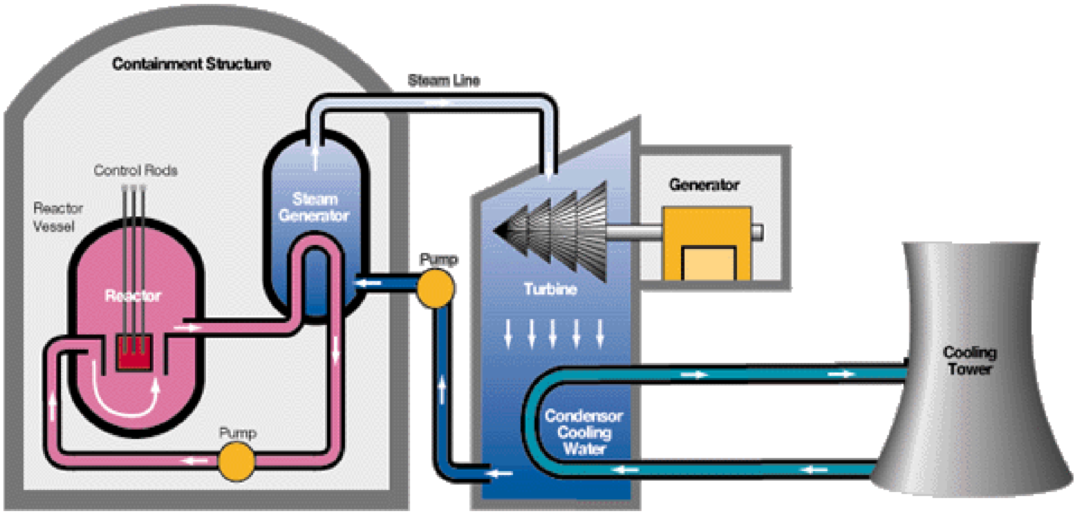


Figure 3.3: Pressurized Water Reactor Cooling System Configuration [9].

3.4.2 How the PWR Differs From Other Reactor Designs

The Boiling Water Reactor (BWR) is a slightly older design than the PWR and is employed in the US, Japan, and Sweden. The BWR differs from the PWR in a number of ways, but primarily in the configuration of the coolant system. The BWR cooling system is composed of two cooling loops rather than three. The primary cooling loop is closed while the secondary remains open. Figure 3.4 illustrates the configuration of the BWR cooling system.

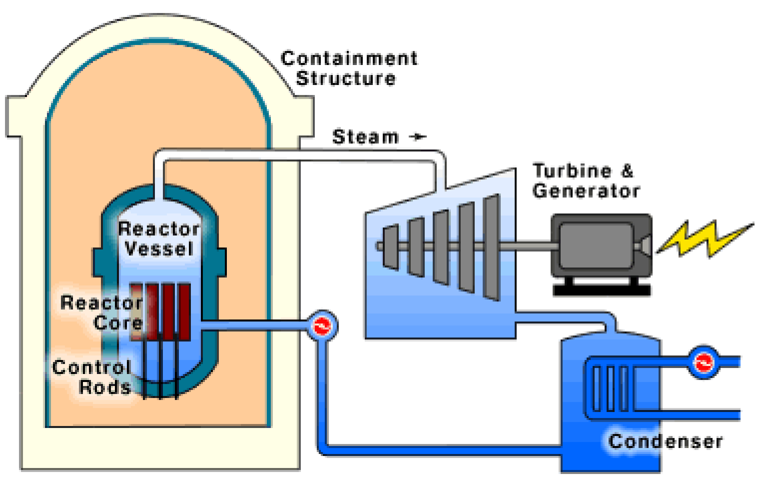


Figure 3.4: Boiling Water Reactor Cooling System Configuration [10].

It can be seen in Figure 3.4 that the placement of the control rods is below the reactor rather than above in Figure 3.3. This is because the BWR relies upon the core itself to generate steam and consequently must allow for the steam to rise and exit above the core which makes upper control rod placement not possible. The difference in control rod placement accounts for the increased safety of a PWR in relation to a BWR because in the event of a malfunction the control rods are allowed to drop into fully engaged position by gravity in a PWR. This gravity assisted safety system is referred to as a passive safety system and is discussed in section 3.6.

The pressurized heavy-water reactor (PHWR) differs from light-water reactors in that the PHWR consumes non-enriched uranium and relies upon heavy water (deuterium) as a neutron moderator. The PHWR requires heavy water because the $^{235}U/^{238}U$ ratio in natural uranium is too low to sustain a continuous nuclear reaction on its own [11].

3.4.3 Advantages over Boiling Water Reactor

The PWR has a higher power density over a BWR due to its relatively compact design. This compact design is largely due to extensive research and development by the United States military for use in marine applications [12]. Another advantage of PWR over other types of reactors is its positive demand coefficient which means power production is directly proportional to power demand within the grid [13]. The PWR also has additional passive safety systems and an additional degree of separation between the core radioactive material and the outside environment made possible by the cooling system configuration. Because the primary coolant loop is highly pressurized, it carries more heat and allows the core to operate at higher temperatures which increases the Carnot efficiency of the reactor.

3.4.4 Disadvantages over Boiling Water Reactor

The PWR is a more complex system than the BWR and as such carries higher costs of construction and operation. Accelerated corrosion within the primary coolant loop is also an issue due to the increased pressure and temperature. To offset the accelerated corrosion, thicker and higher grade materials are required throughout the core and primary coolant loop containment structures. Periodic fuel changing is problematic and carries associated financial losses because the process may take months due to the greater complexities and intricacies of the PWR system. Finally, the thermodynamic efficiency between primary and secondary coolant loops is comparatively low due as a result of the high pressure difference between loops.

3.5 Improvements over previous PWR's and safety system upgrades

The Westinghouse AP1000 nuclear reactor updated its safety systems from previous generation II reactors in several ways. Primarily, the AP1000 differs from most previous PWR's in that the majority of its safety systems rely on passive systems that are always ready without need for human intervention. Generation II reactors are typically more specialized to the location in which they are built. While this seems like it could cut down on costs, the process of redesigning an already existing idea for a PWR can take years and is less cost-effective than fully integrated designs. The AP1000 is more compact compared to other PWR's with similar power outputs. This design also allows for some assembly to be done off-site and lifted into place. The reduced amount of material and smaller footprint make it more affordable with a shorter turnaround rate on returns.

Not only are Generation III+ reactors more cost-efficient, in terms of dollars spent per Gigawatt produced, they also have a longer shelf-life by up to 20 years before major maintenance is required [14]. Generation II designs were originally intended to have a 30-40 year operating lifetime, whereas Generation III+ reactors are designed with the intention of having upwards of 60 years of operation runtime. Systems in a PWR that need replacement or major renovation include the pressurizer vessel, and the steam generators. These components undergo the most amount of stress due to the high pressure in the 'hot leg' and 'cold leg' portion of the heat exchanger unit.

Some Pressurized Water Reactors designed and built by Westinghouse have two, three, or four steam generators to pull heat away from the primary coolant loop [15]. The option to have more than two generators provides backup heat exchanging. The more steam generators and coolant loops attached to the reactor vessel there are, the higher output the nuclear reactor can have. The amount of pressurizers on the primary coolant loops varies from one to two, while the number of primary coolant loops can vary from two to four. Two or more coolant loops are required in more modern PWR's for the added redundancy, giving the reactor a larger safety margin in case of a failure. The AP1000 is outfitted with two steam generators and one pressurizer, but this is beneficial to the safety of the design because all of those components are located inside the steel containment vessel.

3.5.1 Active Safety Systems

The active safety systems in the AP1000 mostly act as gauges to monitor activity within the reactor. From the control room, reactor personnel are able to observe the power output, pressures, heat differences in the cooling agent before and after it leaves the reactor vessel, and many other vital processes in the reactor real-time. One way operators can quickly adjust the power output, and therefore heat generated by the fuel rods, is by lowering the control rods into the reactor vessel incrementally. This gives the operators a fast way to provide damage control or to limit the amount of power generated by the fission process. In conjunction with the control rods, operators have the option to inject neutron poison. A safety injection nozzle, located on the side of the reactor vessel, allows the neutron poison to enter the reactor vessel and spread throughout the chamber, slowing the fission process as it spreads. Many other nuclear reactors implement this type of safety system in order to slow reactions to a lower output level. Most poison injections occur when the reactor is initially coming online after a fuel change in order to reduce the shock on the system when new fuel rods are inserted. The fuel rods eventually burn off the poison and resume full output fission reactions [16].

3.5.2 Passive Water Safety Systems

The nuclear reactor, located within a concrete and steel containment structure, is kept safe by several passive cooling systems put in place above and around the housing structure. In the event of a catastrophic failure, such as a blackout to all power going into the PWR, these passive systems are in place to ensure a meltdown does not occur for the first 72 hours without human interaction. In the event of a blackout, the control rods, held above the reactor vessel by electromagnetic forces, drop into the reactor to halt radioactive fission. Then, in order to keep the steel containment structure from overheating, cisterns located above the nuclear reactor will begin flowing over the outside surface of the housing structure. These large vessels hold enough water to maintain continuous flow for 72 hours. If power has not been restored within the 72 hour period, action is required from nuclear reactor personnel. On-site generators can be started by reactor personnel in order to replenish the cisterns above the housing structure from a reserve tank. This reserve tank contains enough water to cool the housing structure for an additional four days. The combination of these two systems provides seven days of reactor stability without outside power [17] [18].

The configuration of the containment structure, including the outside concrete housing and the inner steel containment structure, are positioned in a way that allows for natural convection to cool the reactor. The bottom of the steel containment structure contains all vital systems to generate power and remove heat from the reactor vessel. The upper portion of the steel containment structure is mostly empty to allow the air inside to rise when it has been heated by the reactor vessel, and fall when the water-cooled walls cool the air. Between the steel and concrete layers of the containment structure is a narrow gap that allows cool air to be drawn in from outside as warm air and water vapor exits the top of the structure. The natural convection that occurs when steam exits the top of the housing structure and cooler outside air enters through the vents is what keeps the steel containment structure so redundantly cool. Figure 3.5 shows an AP1000 steel housing containment structure.

Figure 3.5: Steel & Concrete Housing Containment Structure [19].

3.5.3 Radiation Containment & Storage

After fuel rods are expended in the reactor vessel, they must be disposed. This lower quality uranium can be recycled to be separated into more usable, low quality uranium and radioactive waste, also called radwaste. The low quality uranium can be used in smaller quantities for medical purposes and the radwaste must be disposed of permanently. Before this separation can happen, the fuel rods are too hot when they leave the reactor vessel. The fuel rods are stored for one to ten years in spent fuel pools that are located either on site, or at separate cooling pool locations. These pools hold the hot fuel rods fourteen feet below the water surface. Once the hot radioactive material has cooled and been separated, it is stored in aboveground dry casks. Dry cask storage involves a 15-20 foot tall cement cylinder of radioactive-leak resistant cement. Inside the cement layer is a steel barrier to further protect the radwaste material. Inside that barrier, the small radioactive cylinders are stacked and separated by similar material to what is in the control rods in the reactor vessel.

3.6 AP1000 Technical Specifications

Number of reactors: 2 plus 1 option

Reactor type: Pressurized Water Reactor (PWR)

Power output per reactor: 1117 MWe

Moderator: Light Water

Reactor pressure: 2250 psi

Cooling tower water requirements: 2.27 to 3.8 L/kWh (0.60 to 1.00 gal/kWh) [20]

Fuel type: Enriched Uranium

Control rod material: Boron

Startup pump volume requirement: 260 gpm

Service water system pumps: 7200 gpm

Passive coolant tank volume: 560,000 gal

Required operator response time: 72 Hours

3.7 Summary

The AP1000 pressurized water reactor manufactured by Westinghouse is a safe and efficient reactor for use in the blue castle project. Each enriched uranium powered reactor unit is capable of producing up to 1117 MWe of electricity. The AP1000 is a more compact design compared to previous models of similar power output reactors. This translates to a smaller overall facility and a reduction in material usage during construction.

In addition to the active control and safety systems such as the control rod actuators and coolant pumps, the system has numerous passive safety systems that require no operator input for up to 72 hours. In a serious event the control rods will drop into the reactor core using a powered ram and failing that, explosive bolts and gravity. The control rods are designed to fall into the reactor core aided by gravity in the event of a breach in power to the control rod actuator because the assembly is held in place by electromagnets. Large water cisterns that are located above the reactor chamber flood the compartment and will prevent reactor core meltdown for up to 72 hours. After those 72 hours, more water will have to be pumped in, this water is stored on site and can last for an additional four days.

Taking into account the robustness of safety systems and built-in redundancies of the AP1000 pressurized water reactor, this reactor is both sufficiently safe in terms of human and environmental risk. If operated by protocol and properly maintained, the AP1000 pressurized water reactor poses no threat to society.

3.8 References

[1] Blue Castle, "Blue Castle Project," Blue Castle, 2015. [Online]. Available: http://www.bluecastleproject.com/. [Accessed 19 April 2015].

[2] Westinghouse, "AP1000 Nuclear Power Plant," Westinghouse, 2015. [Online]. Available: http://www.westinghousenuclear.com/New-Plants/AP1000-PWR. [Accessed 19 April2015].

[3] M. C. T. S. W.E. Cummins, "Westinghouse AP1000 Advanced Passive Plant," Westinghouse Electric Company, LLC, 4 - 7 May 2003. [Online]. Available: http://nuclearinfo.net/twiki/pub/Nuclearpower/WebHomeCostOfNuclearPower/AP1000Reactor.pdf. [Accessed 8 April 2015].

[4] Westinghouse, "Optimized ZIRLO High-performance Fuel Cladding Material," Westinghouse, 2015. [Online]. Available: http://www.westinghousenuclear.com/Portals/0/operating%20plant%20services/fuel/fuel%20products/NF-FE-0046%20Optimized% 20ZIRLO%20HP%20Fuel%20Clad%20Mtl.pdf. [Accessed 8 April 2015].

[5] Rensselaer Polytechnic Institute, "Nuclear Energy Advanced Moding and Simulation @ RPI,"Department of Mechanical, Aerospace, and Nuclear Engineering, 2015. [Online]. Available: http://homepages.rpi.edu/~jiw2/group.html. [Accessed 8 April 2015].

[6] J. Grayson, "Control Rods in Nuclear Reactors," Stanford University, 2011. [Online]. Available: http://large.stanford.edu/courses/2011/ph241/grayson1/. [Accessed 9 April 2015].

[7] Union of Concerned Scientists, "Pressurized Water Reactor," Union of Concerned Scientists,Unkown. [Online]. Available: http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nuclear_power/pwr-intro.pdf. [Accessed 9 April 2015].

[8] World Nuclear Association, "Nuclear Power Reactors," January 2015. [Online]. Available: http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Nuclear-Power-Reactors/. [Accessed 14 April 2015].

[9] Nuclear Tourist, "Pressuized Water Reactor (PWR)," Nuclear Tourist, Unkown. [Online]. Available: http://www.nucleartourist.com/type/pwr.htm. [Accessed 11 April 2015].

[10] Nukeworker.com, "Boiling Water Reactor," Unkown. [Online]. Available: http://www.nukeworker.com/pictures/displayimage-477-5313.html. [Accessed 11 April 2015].

[11] Canadian Nuclear Association, "Types of Reactors," Canadian Nuclear Association, 2015. [Online]. Available: https://cna.ca/technology/energy/types-of-reactors/. [Accessed 18 April 2015].

[12] World Nuclear Association, "Nuclear Powered Ships," World Nuclear Association, January 2015. [Online]. Available: http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Transport/Nuclear-Powered-Ships/. [Accessed 18 April 2015].

[13] Bright Hub Engineering, "Types of Nuclear Power Plants - Pressurized Water Reactor," Bright Hub Engineering, 10 September 2008. [Online]. Available: www.brighthubengineering.com/power-plants/2429-types-of-nuclear-power-plants- pressurized-water-reactors-pwr/. [Accessed 18 042015].

[14] R. R. Stephen M. Goldberg, "Nuclear Reactors: Generation to Generation," American Academy of Arts and Sciences, 2011. [Online]. Available: https://www.amacad.org/pdfs/nuclearReactors.pdf. [Accessed 28 April 2015].

[15] M. Ragheb, "Pressurized Water Reactors," 9 March 2015. [Online]. Available: http://docsfiles.com/view.php?view=http://mragheb.com/NPRE%20402%20ME%20405%20Nuclear%20Power%20Engineering/Pressurized%20Water%20Reactors.pdf&keyword=for%20pressurized%20water%20reactors&count=. [Accessed 28 April 2015].

[16] United States Nuclear Regulatory Commission, "Nuclear Poison (or neutron poison),"U.S.NRC, 20 March 2015. [Online]. Available: http://www.nrc.gov/reading-rm/basic-ref/glossary/nuclear-poison-or-neutron-poison.html. [Accessed 28 April 2015].

[17] Westinghouse, "AP1000 Nuclear Power Plant," 2015. [Online]. Available: http://www.westinghousenuclear.com/New-Plants/AP1000-PWR. [Accessed 5 April 2015].

[18] J. Buongiorno, "PWR Description," Michigan Intitute of Technology, [Online]. Available: http://ocw.mit.edu/courses/nuclear-engineering/22-06-engineering-of-nuclear-systems -fall-2010/lectures-and- readings/MIT22_06F10_lec06a.pdf. [Accessed 28 April 2015].

[19] R. Edwards, "New Nukes," MIT Technology Review, 20 October 2008. [Online]. Available: http://www.technologyreview.com/article/411028/new-nukes/. [Accessed 28 April 2015].

[20] World Nuclear Association, "Cooling Power Plants," World Nuclear Association, 28 April 2015. [Online]. Available: http://www.world-nuclear.org/info/Current-and-Future-Generation/Cooling-Power-Plants/. [Accessed 28 April 2015].

[21] Division of New Reactor Licensing, "Final Safety Evaluation Report Related to Certification of the," U.S. Nuclear Regulatory Commission, Washington, DC, 2004.

[22] Westinghouse, "AP1000 Nuclear Power Plant," Westinghouse, 2015. [Online]. Available: http://www.westinghousenuclear.com/New-Plants/AP1000-PWR. [Accessed 28 April 2015].

Chapter 4

A Case Study of the Vogtle Power Plant for the Blue Castle Site

Abstract

This chapter conducts a case study of the Vogtle Nuclear Power Plant to provide a better understanding of the design and layout of the proposed Blue Castle site plan and the function of key buildings. The Vogtle Power Plant expansion was chosen to conduct this case study because it is expected that the Green River Power Plant proposed by Blue Castle Holdings (BCH) will have a similar site design, location, construction timeline and will use the same AP1000 reactors.

Blue Castle Holdings proposes a project for a nuclear power plant near Green River, Utah. The power plant will use two AP1000 reactors made by Westinghouse Company, but the site design is still in its conceptual phase. Thus a case study was conducted to provide a better analysis for the new site in Emery County. The analysis is based on Plant Vogtle located in Georgia, which is currently adding two additional AP1000 nuclear reactors. This study analyzes the site plan and design of Vogtle Units 3 & 4, which allows a direct comparison to the Green River site plan proposed by BCH. The analysis will include an explanation of the function and design of the key structures of the entire power plant. A concise explanation will be provided for all buildings in the power plant and a more in depth description will be provided for the nuclear island and the cooling towers.

4.1 Introduction

Utah, a coal generating state, uses coal to generate most of its energy through coal burning power plants and the demand for energy will increase due to the expected increase in population. A nuclear power plant will allow Utah to create clean energy in order to meet the expected demand. Blue Castle Holdings, a Utah based company, is striving to locate a nuclear power plant in Emery County just minutes Northwest of Green River, Utah. A site location has been chosen and the design and layout has entered the conceptual phase.

Blue Castle has announced a partnership with Westinghouse to install two AP1000 reactors. Due to limited information available on the Green River Power Plant, a case study of Vogtle Power Plant was conducted because this power plant is currently undergoing an expansion that will use identical reactors. A power plant consists of several integrated buildings that work together to produce energy in a safe and effective manner. Within these buildings lies the Reactor surrounded by the Nuclear Island, which is composed of the Containment, Auxiliary, and Shield buildings. Neighboring the Nuclear Island are the Annex, Turbine, Generator and the Radwaste buildings, which are used to control nuclear waste and generate power.

The functioning and design of the cooling towers, and the tertiary water cycle are analyzed because they help keep the main condenser within a safe temperature. This study was also based on Vogtle Power Plant. Based on the climate studies for Emery County, freezing weather operations will be required for the cooling towers to prevent hazardous ice formation. The factors and operations that contribute to manage the ice formation will be explained along with the types of cooling towers and how they function.

4.2 Case Study of Vogtle Power Plant

4.2.1 Introduction

The Vogtle Nuclear Power Plant, located near Waynesboro, Georgia is currently operated by Southern Nuclear, owned by Georgia Power. Plant Vogtle opened for commercial operation in May 1987- 1989, and consisted of two reactor units capable of generating a combined 2,400 MW. The existing units, called units 1 and 2, consist of two Westinghouse 4-Loop reactors also known as a pressurized water reactor. These two units also include twin natural-draft cooling towers (548 ft. tall) and provide cooling to the plants main condensers [1].

In 2008 Southern Nuclear announced that it had submitted a plan for an expansion of the Vogtle Power Plant. Georgia Power came to an agreement with Westinghouse for two AP1000 reactors which are capable of producing 1,100 MW's each. Construction for these reactors, which will be the first nuclear reactors built in the U.S. in the last three decades, [2] has already begun as of this print date and is predicted to finish by 2017-2018 baring no delays.

4.2.2 Case Study of Vogtle Power Plant

On August 20, 2014, Westinghouse Electric Company and Blue Castle Holdings announced the signing of a Memorandum of Understanding to pursue the development of a two-unit AP1000 nuclear power plant at the Green River site in Utah [3]. Because of the choice of new reactors for the Vogtle power plant and because is has been chosen for the Blue Castle Site, the Vogtle site is a test bed for a case study of the power plant proposed for construction in Emery County.

4.2.2a Locations

The design, construction and layout plan of the Vogtle site of their AP1000 should be a basic plan for the Blue Castle site because of the similarities between the two. Vogtle Plant is located southeast of

Augusta, Georgia in Waynesboro along the Savannah River. The owners of Plant Vogtle have entered into a Safe Harbor Agreement with the Georgia Department of Natural Resources to help protect federal endangered species in that area [4]. The proposed plant in Utah also will be located near a river, the Green River in Emery County and the actual site is located, for now, about 5 miles NW of the city of Green River, Utah. The problems associated with Vogtle in trying to get their water rights when they began back in the 80's will be approximate to what Blue Castle Holdings will have to do in order to obtain theirs as well. Also because of the endangered species near Plant Vogtle it could be used as a basis for BCH if they have this same problem arise.

4.2.2b Modular Construction

The design of the AP1000 is modular and that (means) various features have been incorporated in the design to minimize construction time and total cost by eliminating components and reduce bulk quantities and building volumes, [36]. The way things are built at the Vogtle site will be comparable to how they will be built at Blue Castle. Westinghouse Electrics' business model, 'Buy Where We Build', commit(s) to localization of major equipment and engineering services, (and) is an economic stimulus package in and of itself [6]. What this means for both sites is; most if not all of the construction, both materials and actual building, will be completed on site which becomes a major boon for the local economy. The first things built at the plant will be the modular buildings where the raw materials will be brought too in order to help start the building process sooner and finish faster. Another way modular components are delivered to the project is by rail, both Vogtle and Blue Castle projects are near a rail head which makes major structural modules easier to deliver.

4.2.2c Employment

According to Georgia Power the construction project currently at Plant Vogtle is one of the largest job-producing projects in Georgia and employs 5,500 people and will create 800 permanent jobs when the plant finally opens and begins operation [7]. Blue Castle and the surrounding areas can expect similar numbers to these for their employment rates when their project becomes reality.

4.2.2d Construction Timeline

The timeline on construction milestones (at Plant Vogtle) is approximately 59% done, at the time of this printing, and the procurement of the major components is essentially complete [7], however since the project started in August of 2009 the project has been delayed a couple of times, enough to push the operating start time back to sometime in 2019 for Unit 3 and 2020 for Unit 4. The timeline has been pushed back because, a lawsuit by dozens of environmental and anti-nuclear groups just after receiving their Combined Construction and Operating License or COL and also by typical construction delays. Blue Castle will have these same types of delays happen in their construction process. They have already seen some protests in the area trying to stop the project from going forward and there are some parts of the construction process that is hard to plan for.

4.2.2e Costs

After the paperwork and licensing process was started at Plant Vogtle, The Department of Energy initially demanded a credit subsidy fee, but the demand was ultimately dropped given the financial strength of Southern Nuclear and the Vogtle project [1]. This guarantee in monies could affect the Blue Castle project as they do not have a big backer such as a power company involved in the site or project as of this date. The expected building cost for the new units being built at Vogtle could exceed $14 billion [1] and Blue Castle might expect costs similar to this as safety precautions have increased and more robust designs are wanted because of accidents such as the one at Fukushima.

4.3 Design/Layout and Function of Blue Castle Power Plant

4.3.1 Introduction

Nuclear power plants are one of the most recognizable power generation facilities. The most noticeable part of nuclear plant is the cooling tower; these are easily confused with coal-fired power plants that also used cooling towers. Nuclear and coal power plants tend to place close to waterways, mainly for water extraction purposes. Along with the recognizable cooling towers, these plants have a second structure that is easily noticed as the power generation buildings. One way to identify a nuclear plant is by the reactor, the structure tends to look like a short, circular dome near the cooling towers, with a large warehouse nearby that houses the turbines.

4.3.2 Containment Building

The Containment Building is a large steel structure, usually with a hemispherical dome that is sealed off from the outside atmosphere. The building houses the reactor, reactor cooling systems, and several other key components. It is designed in case of any emergency to contain the escaped radiation. While this building protects the outside world from any situation that may occur inside the reactor, it also protects the reactor from any outside threat such as natural disasters and terrorism.

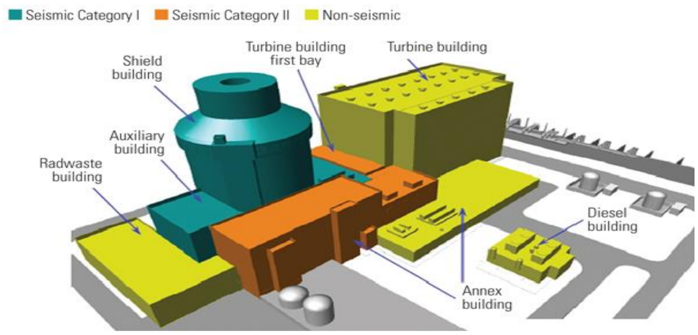


Figure 4.1: AP1000 Site Plan [8].

4.3.3 Shield Building

The Shield Building surrounds the containment vessel and during regular operations it conjuncts with the containment building, by providing the required shielding for the reactor and all other components within the containment structure. This structure also protects the containment building from external hazards.

4.3.4 Auxiliary Building

The Auxiliary Building is separate from the containment and houses much of the support equipment for the reactor. This building is one of the structures that make up the nuclear island and shares a common foundation with the containment building. In general the lower floor of the building houses the laboratories that analyze samples of materials. This is where checks on the air from the radiological isolated environments are made. The upper level of the building houses the areas used for maintenance during fuel changeover operations and the main control room.

Figure 4.2: AP1000 Control Room [9].

The main control room allows workers to work with the interfaces required to operate the plant safely under normal conditions and during accident conditions. The room contains instruments and control systems that control the plant during startup, ascent to power, normal operations, and stabilize the plant during unusual conditions.

4.3.5 Turbine Building

The Turbine Buildings house the main turbine, generator, condenser, condensate, and feed-water systems. It also shields the turbine and major turbine components from harsh weather conditions.

4.3.6 Annex Building

The Annex Building acts as a main entrance for the entire generation complex and includes access to all the structures within the nuclear island. This building includes a hot machine shop to service radioactive equipment from the containment and auxiliary building, the machine shop contains decontamination operations throughout the facility. Also within the Annex Building are large accesses ways to the containment building for access during outages and equipment exchange.

4.3.7 Radwaste Building

The Radwaste Building contains facilities of storage of various types of waste that will process for proper disposal. Some types of the waste that are handled within the building are:

- Contaminated laundry
- Dry waste
- Hazardous waste
- Chemical waste
- Empty waste containers [10]

The waste will be handled and stored in proper containers and prepared to be shipped out to the proper disposal sites.

4.3.8 Diesel Generators building

The Diesel Generator building contains two paralleling diesel generators and according to the APC, "the generator building shields the generators with a three-hour long fire wall" [10]. The fire wall of the building will protect the two backup power generators in case the plant encounters an incident. These generators provide backup power to the plant in the event of unusual operating conditions.

4.3.9 Discharge Structure

Water pollutants, such as heavy metals and salts, build up in the water used in the nuclear power plant systems. These water pollutants, as well as the higher temperature of the water discharged from the power plant, can negatively affect water quality and aquatic life. Although the nuclear reactor is radioactive, the water discharged from the power plant is not considered radioactive because it never comes in contact with radioactive materials.

Figure 4.3: Evaporation Ponds [11].

After the water leaves the plant, the liquid contains particulate that needs to be removed and the needs to cool off. The water then flows into the discharge ponds to allow the particles to settle and the water to cool to a proper temperature. After these two requirements have been fulfilled, the water can either be re-circulated through the plant or discharged back into the environment by evaporation ponds.

4.4 Nuclear Island and Its Components

4.4.1 Introduction

The nuclear island is the only Seismic Category I structure making it the most important structure in the design and layout of an AP1000 nuclear power plant [12]. The complex, which consists of the containment building, the shield building and the auxiliary building, is designed to withstand the worst natural disasters and terrorist attacks. This section will cover the specifications such as materials, dimensions and functions of each one of these structures.

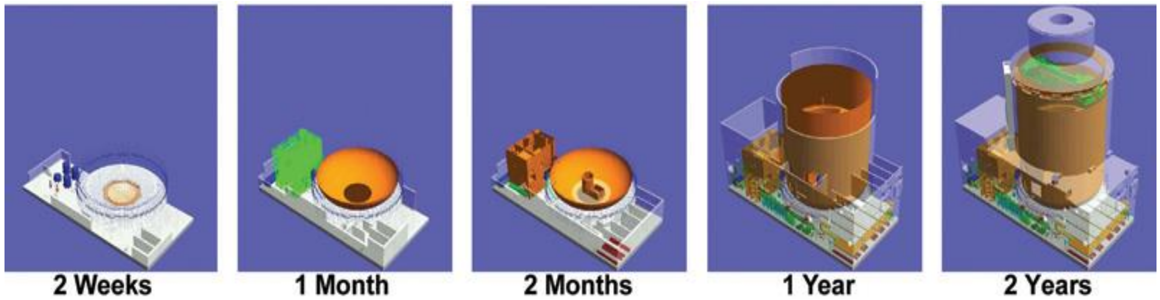


Figure 4.4: Nuclear Island: Construction Timeline [12].

4.4.2 Containment Building

The Containment Building is the most important component of the nuclear island and acts as the final barrier to radioactive release in case of an accident [13]. Also known as the containment vessel, this structure is a reinforced steel cylindrical vessel composed of the cylinder body and two heads. The thickness of the wall is 1.75 inches in most of the cylinder with the exception of the lowest course of the shell where the thickness is 1.875 inches and the thickness of the heads is 1.625 inches [14]. To make the vessel a freestanding structure, the bottom head is embedded in concrete to an elevation of 100 feet, it contains two equipment hatches (one is at the operating floor and the other at an elevation of 107 feet 2 inches) with diameters of 16 feet and consist of a cylindrical sleeve with a pressure head bolted on the inside of the vessel [14]. The design characteristics are listed below:

- Diameter: 130 feet
- Height: 215 feet 4 inches
- Design Code: ASME III, Div. 1 Material: SA738, Grade B
- Design Pressure: 59 psig
- Design Temperature: 300°F Design External Pressure: 2.9 psig [14]

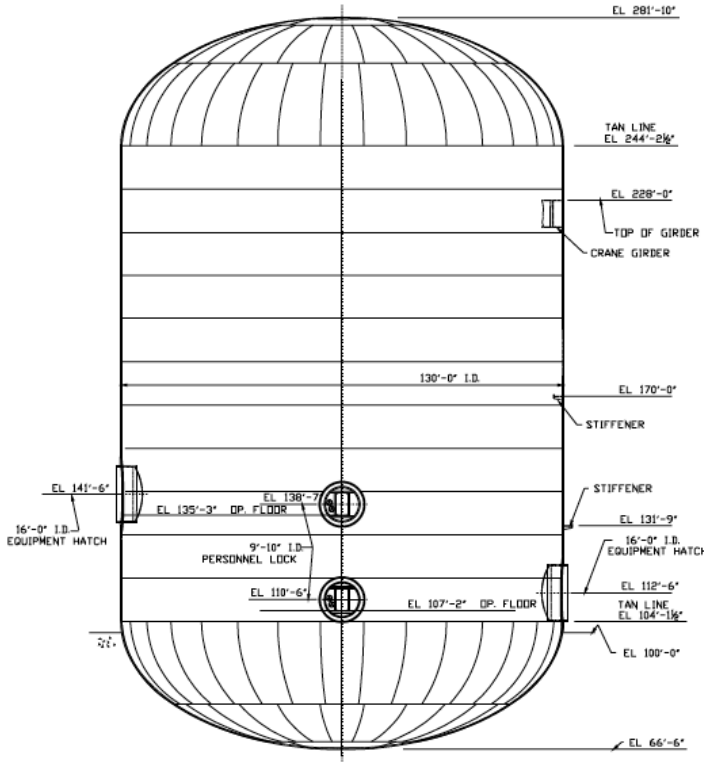


Figure 4.5: Containment Vessel: General Outline [14]

4.4.3 Shield Building

Another component of the nuclear island is the Shield Building, which is a reinforced concrete structure that surrounds the containment building. The cylindrical wall of this structure is mainly a missile barrier, designed to withstand terrorist attacks such as missiles or planes crashing into the reactor [15]. The shield building also functions as a support for the roof and serves as a major structural member of the nuclear island [14]. The roof is also a reinforced concrete shell that supports the passive containment cooling system tank and air diffuser. The air diffuser is located in the center of the roof and discharges containment cooling air upwards and the passive containment cooling system tank has a stainless steel liner which provides a barrier on the inside surfaces of the tank [14]. The following are the significant features and the principal systems and components of the shield building:

- Shield building cylindrical structure

- Shield building roof structure
- Lower annulus area
- Middle annulus area
- Upper annulus area
- Passive containment cooling system air inlet
- Passive containment cooling system water storage tank
- Passive containment cooling system air diffuser
- Passive containment cooling system air baffle
- Passive containment cooling system air inlet plenum [14]

The design of the shield building is very important and should be done with extra care because it protects the containment building, which houses the reactor. The design allows for protection against natural disasters and terrorist attacks, it helps to keep the reactor cool using its air diffuser, it serves as a major structural component for the whole nuclear island and it holds passive containment cooling system that can be used to cool the reactor in case of an emergency.

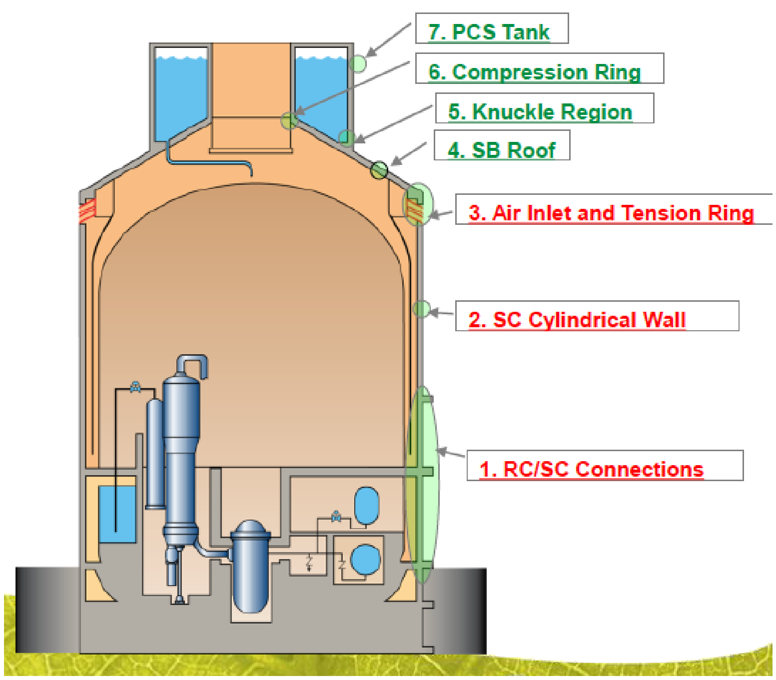


Figure 4.6: Shield Building: General Outline [15].

4.4.4 Auxiliary Building

The Auxiliary Building is the third and last component of the nuclear island, it is the C shape structure that surrounds 50% of the shield building. The floor slabs and structural walls are structurally connected to the cylindrical section of the shield building. The Building consists of five floors, three above grade and two below grade. One side of the structure is composed mostly of structural modules, which are structural elements built up with welded steel structural shapes and plates [14]. These modules are used for the spent fuel pool, the fuel transfer canal and the cask loading and cask washdown pits. The thickness of the structural wall modules ranges from 2′-6′′ to 5′-0′′, the structural modules extend from elevation 66′-6′′ to elevation 135′-3′′, and the minimum thickness of the faceplates is 0.5” [14]. The ceiling of the main control room and the instrumentation rooms are designed as finned floor modules, meaning it consists of a 24-inch-thick concrete slab poured over a stiffened steel plate ceiling [14]. The new fuel storage area is a separate reinforced concrete pit providing temporary dry storage for the new fuel assemblies [14]. The design of the auxiliary building is done with extra care because it houses many important systems and components that control the nuclear plant. The following are the significant features and the principal systems and components of the auxiliary building:

- Main control room
- Remote shutdown room
- Class 1E dc switchgear
- Reactor trip switchgear
- Reactor coolant pump trip switchgear
- Main steam and feedwater piping
- Main control room heating, ventilating, and air conditioning (HVAC)
- Class 1E switchgear rooms heating, ventilating, and air conditioning
- Spent fuel pool

- Fuel transfer canal
- Cask loading and washdown pits
- New fuel storage area
- Cask handling crane
- Fuel handling machine
- Chemical and volume control system (CVS) makeup pumps
- Normal residual heat removal system (RNS) pumps and heat exchangers
- Liquid radwaste tanks and components
- Spent fuel cooling system
- Gaseous radwaste processing system
- Mechanical and electrical containment penetrations [14]

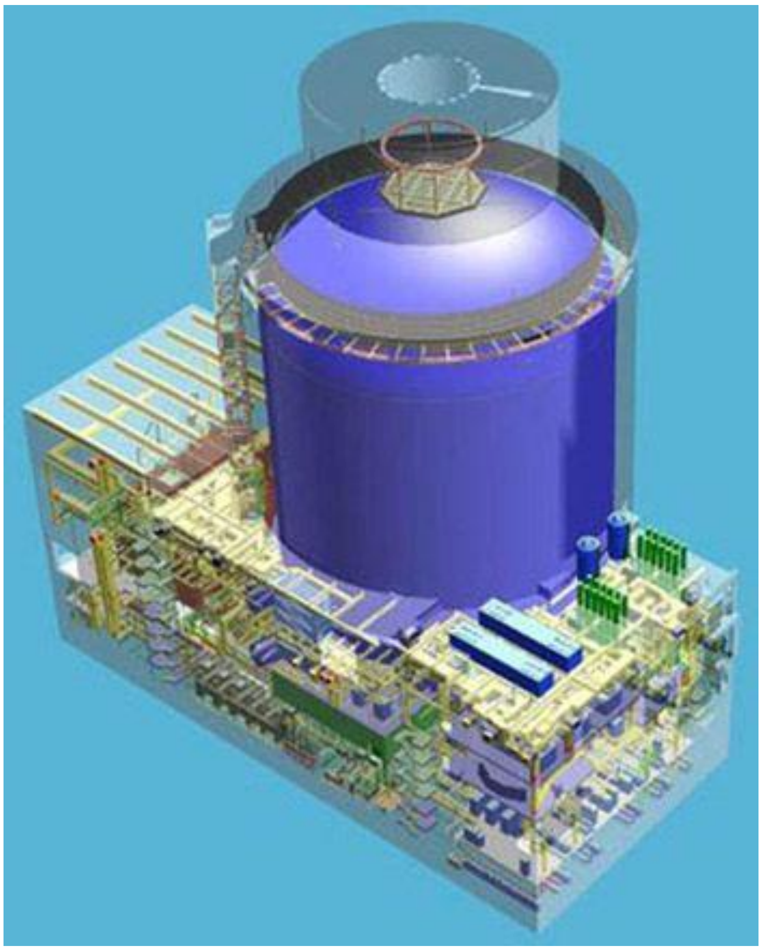


Figure 4.7: Nuclear Island: 3D picture of Auxiliary building [12].

4.5 Cooling Towers and Water Circulation

4.5.1 Introduction

In nuclear power plants, water circulates through three basic closed loop water systems. The closed water system keeps the nuclear reactor within a safe temperature and prevents release of contaminated water to the environment. As discussed in the previous chapter, the primary circuit is used as a Reactor Cooling System, which then flows through the secondary circuit to lower the pressurized water temperature. The water in the secondary circuit circulates from the condenser, at a cold temperature, is heated to steam that runs the turbine, then it gets re-condensed to repeat the cycle. By this process, the condenser will constantly need a cooling system, which is the main purpose for a tertiary circuit. Water in the tertiary circuit is usually cooled by cooling towers or artificial cooling ponds. Cooling ponds not only consume a larger area but can contaminate the environment in the case of nuclear accidents, which is why most nuclear plants use cooling towers. This section will explain the functioning and design of the cooling towers, and the tertiary water cycle in Blue Castle Project, based on the case study of Plant Vogtle. The last part of the section discusses the necessary operations on the towers under freezing weather conditions.

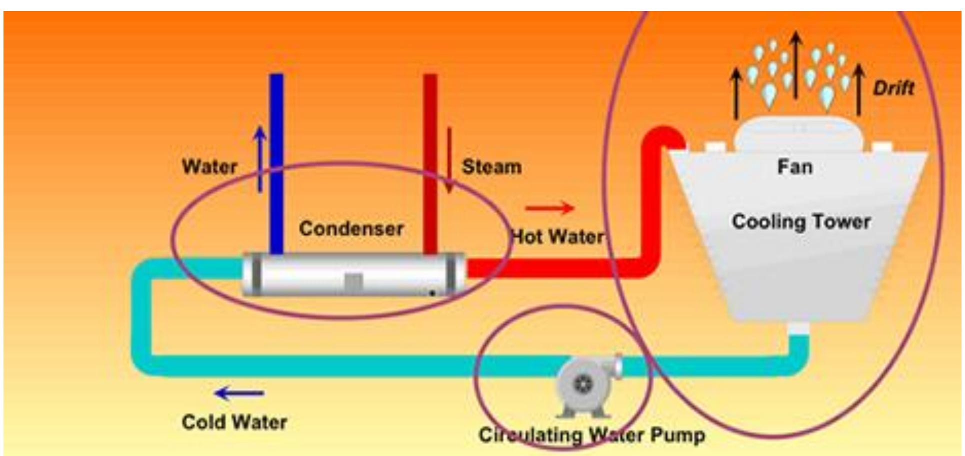


Figure 4.8: Tertiary water circuit [16].

4.5.2 Cooling Towers function and design

Cooling towers are heat exchanging systems that use air to lower the temperature of water used in the plant and reject thermal energy to the atmosphere. There are two major kinds of cooling towers which are natural-draft and mechanical-draft. The processes for both systems are done by pumping water from an outside source and spraying it down to flow over large water fills, which allows it to be exposed to cooling air [18]. The bottom of the tower has openings that allow cold air to flow through it to cool the warm sprayed water.

In mechanical-draft towers, fans are used to force air to flow through the tower at higher velocities, these cooling towers are called force-draft towers. The other type of mechanical-draft cooling towers use fans at the top to pull the warm air out of the tower, called induced-draft towers. In natural-draft towers, mechanical devices are not needed, and the process is done by convection. Convection is natural process within a fluid that allows hotter (less dense) materials to rise, and colder (more dense) materials to sink under the influence of gravity. Due to the difference in air density in the tower, warm air at the bottom rises up and exits the tower, allowing cold air to continually flow and cool the water.

Figure 4.9: Bottom of a Natural-draft Tower: air cooled water falling off the fills [23].

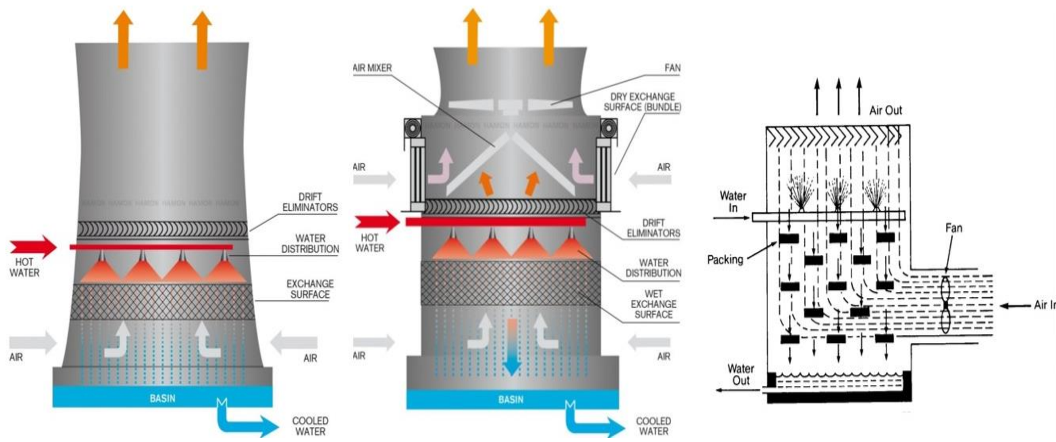


Figure 4.10: Air Cooling Process: a. natural-draft b. induced draft c. forced-draft [17] [18]

Mechanical-draft towers are more efficient due to the fast flowing air that is forced by fans, which effectively cools the water faster. Natural Draft towers eliminate the need for mechanical devices by relying on natural air flow, but needs to be built bigger to generate equivalent amount of cooling. The hyperboloid Natural-draft towers structures can be up to 660 ft. tall and 330 ft. in diameter, to increase the heat rejection capacity [18]. The hyperbolic shape helps strengthen the structure and maximize the air draft (cooling efficiency). It is also more economically accessible due to the decreased cross-sectional area at the top. Mechanical-draft towers are usually 110 ft. or smaller [18]. In other plants, mechanical towers are designed in rectangular structure that can be over 130 ft. tall and 260 ft. long.

(a)  (b) 

Figure 4.11: Mechanical-draft Tower designs: (a) rectangular structure tower (b) circular structure tower [27] [28].

4.5.3 Cooling Tower systems in Green River Power Plant

The type of cooling towers for the Blue Castle Project is still not officially announced, but because Blue Castle is planning on using the same reactors as Plant Vogtle, it is valid to apply their cooling tower systems for the Green River Plant. Plant Vogtle uses three cooling towers for each reactor, one natural-draft, and two smaller mechanical-draft cooling towers. The natural-draft towers are 548 ft. tall and provide cooling to the plant's main condenser. The mechanical-draft cooling towers provide cooling for auxiliary safety and to remove heat from the reactor when the plant is offline [20]. The site at Green River is expected to have two AP1000 reactors with an additional space for a future reactor. By applying the Plant Vogtle case study to Green River and taking the future reactor in consideration, it should contain three natural-draft cooling towers and six mechanical-draft cooling towers. However, the site plan reveals that the cooling towers are built in a rectangular manner which possibly indicates that only mechanical-draft towers will be constructed at Blue Castle, but it is not officially confirmed.

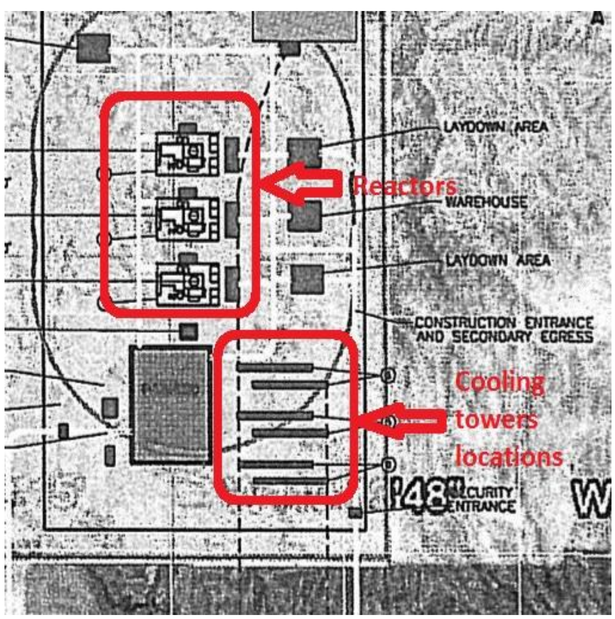


Figure 4.12: Location of reactors and cooling towers at Green River power plant [21].

4.5.4 Tertiary Water Cooling Circuit and Make-up Water

The Tertiary circuit provides cooling for the main condenser and it also allows additional cooling for the steam in the secondary circuit [22]. As water gets heated during the process, it is pumped to the cooling tower to lower its temperature before it circulates back to the condenser. During this cycle, water can be lost by evaporation, drift-loss, and blowdown.

4.5.4a Water loss

About 1-1.2% of the circulating water evaporates to the atmosphere through the heat removal process but, the amount of water evaporated is a function of load on the system which can be controlled by managing the water flow.

Drift-loss is an uncontrollable process that carries out the water when in contact with the air flowing through the tower and the amount of the loss can vary between 0.008-0.2% depending on the design of the tower [24].

Blowdown is a controlled process of removing water with high concentration of minerals and bacteria.

4.5.5 Make-up Water

The quantity of water needed to be added as a result of the lost water is called make-up water [24]. Through a series of engineering calculations the amount of make-up water is calculated; equation (1) shows its' general formula.

Make-up water = Evaporation loss + Drift loss + Blowdown **Equation (1)**

With consideration of the water wasted during the cycle, the tertiary water circuit must still be isolated from direct connection with Green River to prevent any contamination to the environment in case of radiation fallout.

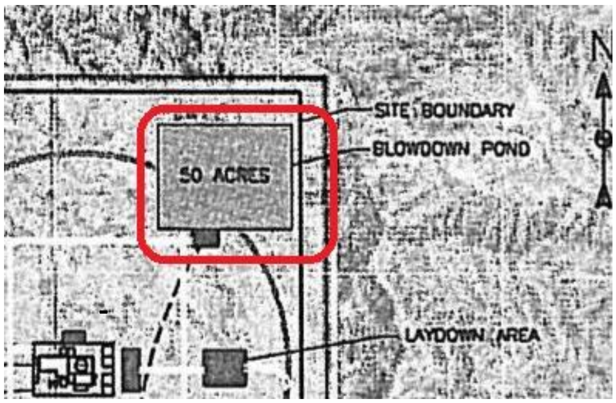


Figure 4.13: Blowdown pond location in Blue Castle site [21].

Blowdown pond

Blue Castle includes a 50 acre artificial pond to store the fluids carried out from the plant through the blowdown process.

4.5.6 Operation in Cold Weather

Cooling towers operate continuously even during freezing weather, and it is the plant operator's responsibility to monitor and use the proper procedures to prevent build-up of ice formations and prevent freezing. The average low temperature in the Green River region during the winter season varies between 12-31°F, which makes it necessary to consider freezing climate operations. Thin cross-sections of ice usually develop on the structures and water fills, which can be considered acceptable. Thin-ice formation must be constantly checked to prevent cross-section increase, and ice should never be allowed to develop on mechanical devices. Without constant monitoring, massive formations of ice can block the air flow and can cause structural damage and even collapse [25].

Figure 4.14: Hazardous Ice Formation: massive formation can block air from flowing through [26].

To prevent the problem, many factors must be taken in consideration:

- Outside air and cold water temperature; lower temperature increases ice formation
- Water flow; the reduction of water flow increases ice formation
- Air flow rate; reduced air flow slows ice formation
- Heat load; heat load reduces ice formation [26]

In mechanical-draft towers, air flow manipulation technique is used to slow the rate of ice formation. In natural-draft towers air-flow is uncontrollable, which makes it mandatory to install cold water basins and basin heaters to increase heat load and prevent water freezing [25]. It is also recommended to install remote sensors and alarms to prevent weather related mechanical issues. If the proper procedure is taken, the cooling towers should be able to continuously operate in winter without causing any major problems to the water circulation.

4.6 Summary

The Blue Castle project has proposed the construction and operation of a two-unit nuclear power plant near Green River, Utah. Plant Vogtle, a nuclear power plant located in Waynesboro, Georgia, has been operational since 1987 with two Westinghouse 4-Loop reactors and is currently building two Westinghouse AP 1000 reactors, the same reactors that the Blue Castle project plans to use. The construction of these two new units began in 2008 and will be completed between 2017 and 2018. This is currently the largest project in the state of Georgia, creating 5,500 jobs during the construction period and a total of 800 once the power plant is completed.

The design and layout of the power plant that Blue Castle Holdings has proposed is expected to be very similar to the expansion currently occurring at Plant Vogtle. The design and layout consists of garages, warehouses, cooling towers and a group of buildings that house the reactor. These buildings include the turbine building which houses the turbine, the annex building which acts as the main entrance to the entire generation complex and the radwaste building which contains facilities used to store waste. The nuclear island is the most important portion of this group of structures. It is composed of the containment building which acts as the last barrier in case there is a nuclear leak, the shield building which protects the containment building against any terrorist missile attacks and the auxiliary building which contains some of the most important rooms such as the control room. Finally, the design also contains cooling towers, which are used to cool the water used to cool the reactor, a discharge pond, used to let the sediments settle before the water is brought into the reactor and a discharge pond, which is used as a place to dump the water that will no longer be used so it can evaporate without causing any damage to the environment.

4.7 References

[1] "Vogtle Electric Generating Plant -Wikipedia, the free encyclopedia," [Online]. Available: http://en.wikipedia.org/wiki/Vogtle_Electric_Generating_Plan. [Accessed 14 April 2015].

[2] "Vogtle-nuclear-brochure," [Online]. Available: http://www.southerncompany.com/nuclearenergy/. [Accessed 14 April 2015].

[3] "Westinghousenuclear.com," [Online]. Available: http://www.westinghousenuclear.com/About/News/View/Westinghouse-Blue-Castle-Work. [Accessed 14 April 2015].

[4] “Plant Vogtle,” [Online]. Available: http://www.southerncompany.com/about-us. [Accessed 21 April 2015].

[5] "Westinghouse.com," [Online]. Available: http://www.Westinghouse.com. [Accessed 14 April 2015].

[6] "Westinghouse –Nuclear | Westinghouse Electric Company," [Online]. Available: http://www.westinghousenuclear.com/New-Plants/Engineering-Construction. [Accessed 14 April 2015].

[7] "Vogtle-Units-3-and-4-FactSheet," [Online]. Available: http://www.Vogtle-Units-3-and-4-FactSheet. [Accessed 21 April 2015].

[8] "Legal Eletric," [Online]. Available: http://legalectric.org/weblog/category/nuclear/. [Accessed 21 April 2015].

[9] "ap1000," Westinghouse, [Online]. Available: https://www.ukap1000application.com/psrs_mcrehs.aspx. [Accessed 27 April 2015].

[10] “APC,” Westinghouse, [Online]. Available: http://www.apcnean.org.ar/arch/ 3e139fc91ebe2e675db2194460badc7c.pdf. [Accessed 14 April 2015].

[11] "Nuclear Engineering," [Online]. Available: http://www.neimagazine.com/features/featurean-oasis-filled-with-grey-water/featurean-oasis-filled-with-grey-water-1.html. [Accessed 28 April 2015].

[12] “Westinghousenuclear.com,” [Online]. Available: http://www.westinghousenuclear. com/New-Plants/AP1000-PWR/Economic-Benefits. [Accessed 19 April 2015].

[13] “en.wikipedia.org,” [Online]. Available: http://en.wikipedia.org/wiki/Containment_building. [Accessed 17 April 2015].

[14] "nrc.gov," [Online]. Available: http://www.nrc.gov/reactors/new-reactors/design-cert/ap1000/dcd/Tier%202/Chapter%203/3-8_r14.pdf. [Accessed 12 April 2015].

[15] "iaea.org," [Online]. Available: http://www.iaea.org/NuclearPower/Downloads /Technology/meetings/2011-Jul-4-8-ANRT-WS/2_USA_UK_ AP1000_Westinghouse_Pfister.pdf. [Accessed 22 April 2015].

[16] "Nuclear Reactor Technical Information," [Online]. Available: http://www.onlineethics.org/cms/4612.aspx. [2014].

[17] "Induced draft," [Online]. Available: http://www.hamon.com/en/cooling-systems/wet-cooling-systems/mechanical-draft-cooling-towers/induced-draft-cooling-towers/. [2013].

[18] "Wet Cooling Towers," [Online]. Available: http://www.epa.gov /ttnchie1/ap42/ch13/final/c13s04.pdf. [2013].

[19] "Plant Vogtle 3 and 4," [Online]. Available: http://www.southerncompany.com /what-doing/energy-innovation/nuclear-energy/pdfs/vogtle-nuclear-brochure.pdf. [2015].

[21] "The problem with SR 1735," [Online]. Available: http://legalectric.org/weblog/category/nuclear/. [Accessed 18 March 2015].

[22] "Tertiary water circuit," [Online]. Available: https://quizlet.com/3922186/chapter-11-part-one-flash-cards/.

[23] "Series 3000" [Online]. Available: http://www.baltimoreaircoil.com /english/products/cooling-towers/series-3000/engineering-considerations. [].

[24] "Water using in cooling towers," [Online]. Available: http://www.conservationmechsys.com/wp-content/siteimages/Water%20use%20in%20Cooling%20Towers.pdf. [].

[25] Mettry, Mathue "Cooling towers maintenance in freezing weather," [Online]. Available: http://www.midwesttowers.com/blog/bid/176843/Cooling-Tower-Maintenance-in-Freezing-Weather. [Nov 7, 2012].

[26] "Operating cooling towers in freezing weather," [Online]. [April 2012].

[27] "All Kote lining Inc.," [Online]. Available: http://www.allkoteliningincaz.com/. [].

[28] [Online]. Available: http://spxcooling.com/history/detail/1970s/.

Chapter 5

Legal Aspects and Acquisition of a Water Right

Abstract
The Hydrologic Aspects of the Facility section discusses each aspect of water use for the Blue Castle Project including legal considerations and procurement of a water right, design of the diversion works to convey water to the plant, and environmental effects of that water diversion. The following chapter provides an overview of the entire section, then explores legal considerations of acquiring a water right for Blue Castle Holdings, Inc. These legal considerations include the effects that this water right will have on downstream water users and an analysis of the Colorado River compact. Next, each step of the water rights application process is described from the Application to Appropriate Water, to the advertisement and objection period, and legal requirements for approval. Finally, a completed Application to Appropriate Water for Blue Castle Holdings, Inc. is included.

5.1 Introduction

This chapter will define what a water right is along with the difference between a leased water right and an owned water right. It will also discuss that Blue Castle Holdings, Inc. is using leased water rights and the major considerations that were looked at by the state engineer before he approved the change application for the leased water rights. The process of applying for a new water right is discussed and a completed application is attached.

A water right is a right to divert water at a specific location on a water source and putting it to recognized beneficial use at a set location [2]. There are a few defining elements of water rights; there must be a defined nature and extent of beneficial use, a specified place of use, and a specified point of diversion. A priority date is set based on when the water was first put to beneficial use. The quantity of water allowed for the diversion must be defined by the flow rate and the volume of water. A point of diversion from the water source must be specified. The water rights must be used every seven years or they will be revoked. There is also the option of filing for non-use every seven years.

There are two ways to obtain water rights: to lease them or own them. There are benefits and disadvantages to each of them. For leased water rights there has to be an approved change application stating that these water rights are being leased from the owners. The disadvantages of using leased water rights for the lessee is that the rights can be revoked at any time if the water is needed for other uses with an earlier priority date or if the original owner wants to use the water for other reasons. There are also monthly payments owed to the owner of the rights. At the end, leased water rights are not secure nor an economical solution. Owned water rights have a bigger advantage that the rights cannot be taken back. The only payments that are necessary are the initial filing fees. The disadvantage of owned water rights is that the process is even more strict and is harder to get approved because there is no water that is already accounted for being diverted so the calculations must be made to make sure that the water being diverted will not affect the original water source or the downstream environment.

5.2 Legal Considerations

This section will discuss the water rights that Blue Castle Holdings, Inc. is currently leasing. The major considerations for the change application are also discussed in greater detail.

5.2.1 Leased Water Rights

This nuclear power plant will operate using leased water rights. The change applications have been approved for Blue Castle Holding to lease water rights from Kane County and San Juan County Water Conservancy Districts (KCWCD and SJCWCD) [4]. The original water rights were purchased to run coal burning power plants but they were never constructed, so now Kane County Water Conservancy District and San Juan County Water Conservancy District are facing the problems that either they have to file for non-use and pay that fee or lease out their water rights. When they are leasing their water rights to Blue Castle Holding they are getting the payments from them and are making money on their water.

5.2.2 Green River Watershed

The Green River Watershed spans parts of Utah, Colorado, and Wyoming. The main tributary is the Colorado River. The entire watershed is about 45,000 square miles. There are approximately 70 major dams in this watershed [1]. Since all the dams release a certain amount of water that eventually makes its way into the green river, the flow of the water in the Green River can vary. In order to make sure there are no downstream effects on the river flow. Show in Figure 5.2.1 on the following page is the entire watershed.

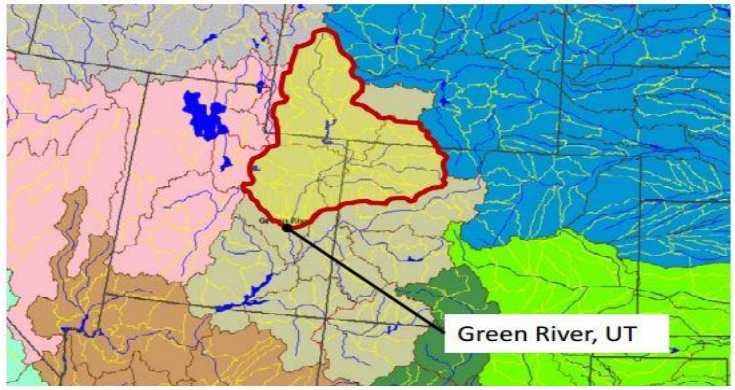


Figure 5.2.1: Green River Watershed [1].

5.2.3 Requirements for Approval of an Application

There are requirements from the Division of Water Rights that must be met in order for the state engineer to approve of the application. This section will analyze each of the requirements from the Water Rights Laws From Title 73 Chapter 3 (Appropriation) Section 8 (Approval or Rejection of application --Requirements for Approval) and look and the protests that became present when the change application was being approved. In order for an application for Blue Castle Holding to have their own water rights they must meet these exact requirements and have them backed by evidence of each requirement in order to be approved by the state engineer. All the requirements come from the Water Rights Law Title 73 [5].

> (1)(a) *It shall be the duty of the state engineer to approve an application if:*
> (i) *there is unappropriated water in the proposed source* [5]

> Protests claimed that there is insufficient unappropriated water in the Green River. They say that the Colorado River Basin is over-appropriated and the amount being taken is more than what was agreed to based on the Colorado River Compact which says how much water can be pulled from the Colorado River in all areas. This was investigated and it was found that Utah may deplete 23% of the flow allocated to the Upper Colorado River Basin States (Utah,

Colorado, Wyoming, New-Mexico, and Arizona). This shows that Utah's share of the river is currently about 1.4 million acre-feet per year. Currently Utah uses about 1 million acre-feet. The water right laws were written specifically and the priority date system will be used in the case that too much water is being diverted. If this happens that owners with the most recent priority dates will have to cut back on their water usage. Since this system is in place, Utah will never exceed their amount of the Colorado River Basin [6].

(ii) *the proposed use will not impair existing rights or interfere with the more beneficial use of the water* [5]

There have been a number of protests claiming that if the approval of this application was done then it would impair the existing rights and interfere with more beneficial uses. The state engineer can approve an application even if the conditions will impair others but will provide compensation the affected parties. This nuclear plant will provide power and is now and has historically been an important part of the economy regardless of whether the plant is a nuclear plant or a coal fired plant which was the original plan for the water rights [6].

(iii) *the proposed plan is physically and economically feasible, unless he application is filed by the United States Bureau of Reclamation* [5]

Some of the protests say that neither the applicant nor the developer own the ground which the plant is proposed to be built on. The State Institutional Trust Lands Administration (SITLA) has leased the project site to Emery County which will allow Emery County to lease the property to the developers. Others protested that the project is not economically feasible. The Energy Policy Act of 2005 offers incentives for the development of new nuclear power plants such as federal loans guarantees for up to 80% of total project costs. Emery County, Green River City, and the Utah Legislature have expressed the support for a nuclear power plant [6].

(iv) *the applicant has the financial ability to complete the proposed works* [5]

The protests have expressed that Blue Castle Holdings, Inc. does not have the financial ability to complete the project. It is said that the cost of construction is to be between $12 and $18 billion. Under this statute it does not require that an applicant has all of the funds immediately to complete the project. The lessee has proven to the state engineer that they have the ability to secure funding as needed [6].

(v) *the application was filed in good faith and not for purposes of speculation or monopoly* [5]

Protests against this statute say that Blue Castle Holdings, Inc. is neither a utility nor a publicly owned company and they intend to sell the site at a future date. They also say that the intend of the application was to obtain a water right and then sell it and claiming that it was not filed in good faith since detailed analyses did not accompany the filing of the application. The applicant has further explained and refined their plans to accomplish the project that is for the application. The water is being used for a beneficially use because the water is being used for the purpose of running the nuclear power plant to generate electricity [6].

(1)(b)*It shall be the duty of the state engineer to reject or withhold approval of an application if:*

(i) *interfere with its more beneficial use for irrigation, domestic or culinary, stock watering, power or mining development, or manufacturing, or will unreasonably affect public recreation or the natural stream environment* [5]

The protests for this statute focused on the public welfare, recreation, and the natural stream environment. According to some, this project would jeopardize the public's health and safety. Protesters argue that if the agricultural and livestock products grown or raised near Green River become contaminated with radioactive materials, it will be detrimental to agricultural interests, the general public, and the local economy. The Nuclear Regulatory Commission (NRC) will address the health and safety issues related to the development of the nuclear power plant. The diversion and use of water will not be detrimental to the public welfare [6].

For recreation along the Green River, the issue was that the diversion of water would reduce the flow of the river and would affect river rafting outfitters and guides. Based on the natural flow of the Green River, the 75 cubic feet per second that will be removed will not change the flow of the river [6]. Downstream from the power plant will not be disturbed and the water quality, river habitat, and endangered fish species will not be affected. The U.S. Fish and Wildlife Service (USFWS) has said that protecting certain flow recommendations will conserve the fish species and their habitat [6].

5.2.3a Other Concerns Raised in Protests

The U.S. Bureau of Reclamation stated that the stored water in Flaming Gorge is released and delivered to Lake Powell each year. They also state that any right to use the stored water released from Flaming Gorge Reservoir must have a water service contract with the U.S. Bureau of Reclamation. The flow at the Green River station averages over 4 million acre-feet per year while only 1.4 million acre-feet per year is released from Flaming Gorge Dam. This shows that most of the water flowing in the Green River comes from other tributaries, so all the water is regulated as part of the flow of the river [6].

5.2.4 State Engineer's Evaluation and Conclusion

Based on all of the requirements that had to be met that were described in section 5.2.3 the state engineer must make a decision to approve or reject the application. The state engineer approved the change application from Kane County and San Juan County Water Conservancy Districts. All requirements were met and there was proof of beneficial use of the water that will be diverted. Since the change application has been approved it is very likely that Blue Castle Holdings, Inc. can apply for its own water right and it will also be approved.

5.3 Water Right Application

The application process for a new water right is much the same as the process for a change application. The following sections will describe the entire process, start to finish, as it applies to the Blue Castle Project.

5.3.1 Introduction

This section will outline the four major steps that compose the water rights application process from start to finish. More specifically, the process will be explained with respect to the Blue Castle nuclear power plant. The first step for acquiring a new water right is to file an Application to Appropriate Water with the Division of Water Rights. Once the Application is approved, the applicant must submit a Proof of Beneficial Use to the Division. During the time allotted to submit proof, the applicant may submit extension requests in order to acquire more time to develop their diversion works. After proof is submitted, the applicant can attain a Certificate of Beneficial Use from the Division of Water Rights that serves as a proof of perfection for their water right. Each section is discussed in more detail in the following sections and a flow chart of the process is shown in Figure 5.3.1 on the following page.

5.3.2 Application to Appropriate Water

To begin the water right process, the applicant must submit an Application to Appropriate Water to the proper regional office within the Division of Water Rights. The regional office in Price is the governing office for the Green River area to which the application will be submitted. The application itself displays the owner's information, specifies where and how the water will be used, and defines the maximum volume per year and maximum flow rate that can be used. An application map must be submitted with the application showing the parcel(s) of land, the proposed place(s) of use, and the proposed point(s) of diversion. A completed Application to Appropriate Water for Blue Castle Holdings, Inc. is included at the end of this chapter in Appendix I.

Once the application has been submitted to the Price office of the Division of Water Rights, the applicant must advertise the application in the newspaper that is local to the area in which the water will be used. The water rights system in Utah is primarily self-policing in that the community of water users monitor new applications and change applications to ensure their water right is not impaired. After the two week advertisement period, proof of publication must be submitted to the Division and a 20 day protest period ensues. When the protest period subsides, each protest must be settled through a hearing that includes the regional office, the applicant, and the protestant. Once the state engineer settles all protests, the regional office works with the application section of the Division of Water Rights to conduct research on the application which includes a review of applicable statutes, protests, and field investigations of the points of diversion, place of use, nature of use, ownership title, and feasibility of the proposed project. After a thorough investigation of the application, the regional office and application section recommend an action to the state engineer based on their findings. In regard to the Blue Castle Project, the

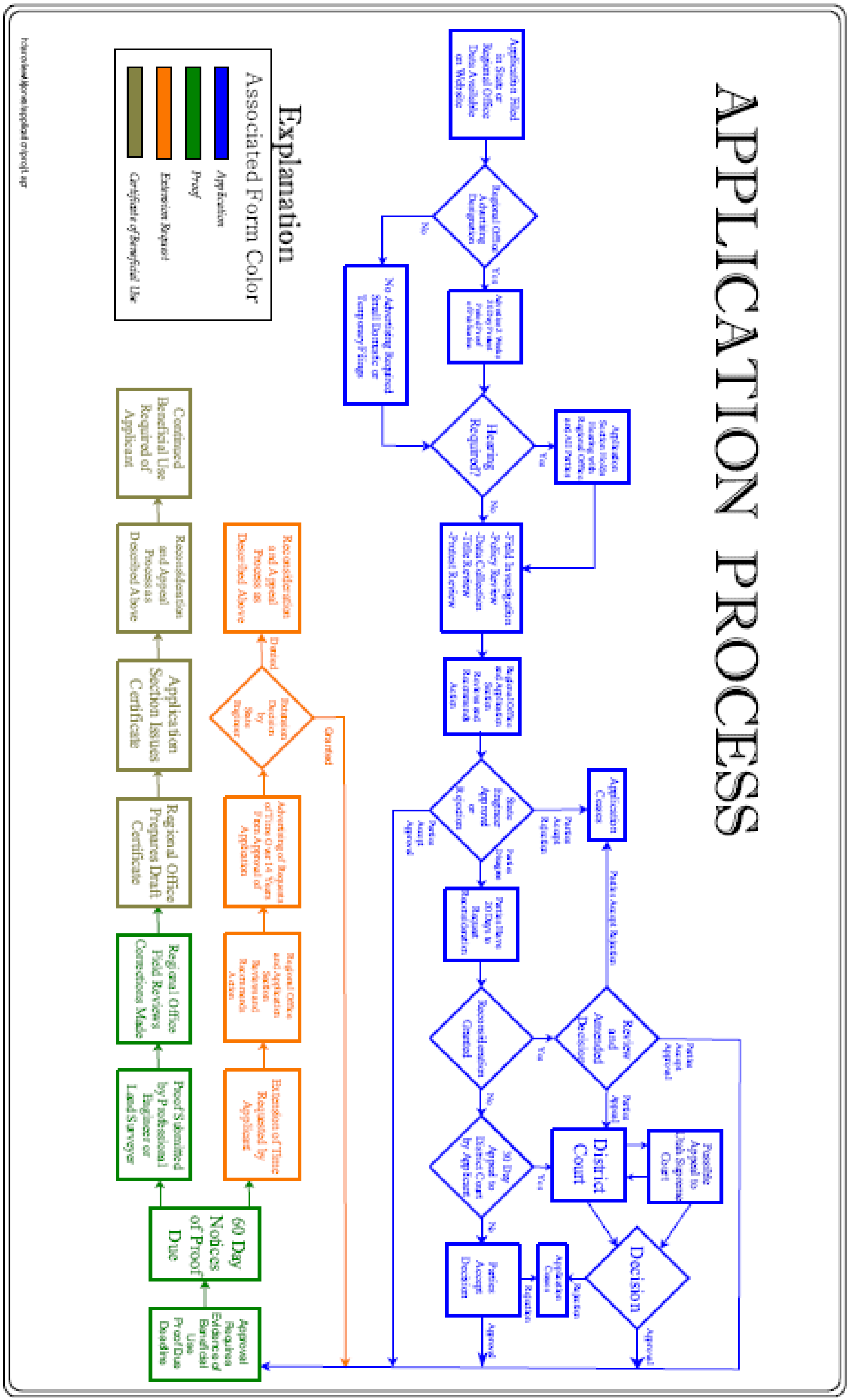


Figure 5.3.1: Application Process Flow Chart [2].

considerations that would be made by the Division of Water Rights are outlined in section 5.2.3. At this point, the state engineer performs his or her own investigation of the application and interprets the statutes that are pertinent to the specific application in order to approve or reject the application. If, at any time, the state engineer approves the application and the applicant accepts the decision, the applicant proceeds to the proof submission step of the process which is described in section 5.3.3. If the application is rejected by the state engineer, the applicant may request reconsideration within 20 days of the decision. If the reconsideration is granted by the state engineer, an additional review is conducted and an amended decision is made. If the application is denied in the amended decision or if reconsideration is not granted, the application will cease unless the applicant appeals to the District Court within 30 days of the decision. At this point, the application is taken before the District Court and possibly appealed to the Utah Supreme Court where the ultimate decision is made to either reject and cease the application process or approve the application and proceed to submittal of proof.

5.3.3 Proof

Submitting a Proof of Beneficial Use is the next step in the process of securing a water right for Blue Castle Holdings, Inc. The applicant has 60 days from the time their application was approved to submit a Proof form and map but proof should not be submitted until all development is completed for the proposed uses described in the application including pumping systems, diversion ditches, storage reservoirs, etc. If development will not be completed in the 60 day period, the applicant can submit an extension request which is described in section 5.3.4. Proof forms can be found on the Division of Water Rights' website (www.waterrights.utah.gov) and include all of the information from the Application to Appropriate Water plus flow rate measurements plus a proof map showing all diverting works and where the water is used. Unlike the Application to Appropriate Water, the Proof of Beneficial Use must be notarized and must be submitted by a professional engineer or land surveyor. All maps submitted to the Division of Water Rights must conform to the Division's mapping standards, which are described in Rule R655-5 of the Utah Administrative Code. The general requirements are defined in section 3.6.1 of statute R655-5-3 shown below:

> *3.6.1 General Requirements. Maps are required when a proof is submitted on an approved Application to Appropriate Water (permanent or fixed time), on an approved Application for Permanent Change of Water, or on an approved Application to Exchange Water. Proof maps must show the specific point(s) of diversion, the place of beneficial use, and the extent of use. Proof maps shall also clearly show any specific information required in the approval of the application (e.g., water metering devices) or information necessary to make clear the manner in which water is diverted, measured, conveyed, and used.* [7]

The applicant's professional engineer or land surveyor submits the Proof of Beneficial Use to the regional office for proofreading and corrections, then the regional office field reviews the proof to ensure its accuracy. Once all corrections are made, the regional office accepts the proof, and begins the certification process explained in detail in section 5.3.5.

5.3.4 Extension of Time Requests

As stated in section 5.3.3, applicants have a 60 day period from the time their application is approved to submit proof. Sometimes, development for the water right has not been completed by the time proof is due, so the applicant may request an Extension of Time for their proof due date. The extension request is submitted to the regional office and the application section for review and a recommendation is made by those offices to the state engineer. If the extension is denied by the state engineer, the applicant may submit reconsiderations and/or appeals as described in section 5.3.2. If the extension is granted, the applicant receives an additional 60 days to submit proof. If proof is not submitted in the time allotted, the application may expire and cease. Extensions may be filed as many times as necessary for development to be completed, but if 14 years or more have elapsed since the original application was approved, the extension requests must be advertised in the same fashion as described in section 5.3.2.

5.3.5 Certificate of Beneficial Use

When the corrected Proof of Beneficial Use is submitted, the regional office drafts a Certificate of Beneficial Use and submits it to the application section which then issues the certificate to the water user. If the water user disagrees with the content of the certificate, they may submit reconsiderations and/or appeals as described in section 5.3.2. Once the certificate is issued, the water right is "perfected" which means that all required steps have been completed and the process of new appropriation is complete. At this point, the water user continues the beneficial use of water consistently with their certificate to ensure that their water right is perpetuated.

5.4 Conclusion/Recommendation

Although Blue Castle Holdings, Inc. has secured water to use in the plant via water rights leased from San Juan and Kane County Water Conservancy Districts, there are important benefits of securing a new water right. A water right leased to Blue Castle Holdings, Inc. can be revoked if the lessor develops a new use for the water, whereas a water right owned cannot be revoked. In the event that the lease is revoked, the power plant must cease operations unless a different water source is procured. Additionally, a new water right is more economical for Blue Castle Holdings, Inc. because they only need to pay for the application process and construction and maintenance of their diverting works which are expenses they must incur anyway. Once the water right is obtained, there is no cost to use the water and they do not have to pay another entity to lease the water. Lastly, a new water right provides security by obtaining an earlier priority date. The water rights that the change applications were filed on have priority dates from 1964 and 2000 but the change applications have a priority date from 2009. The original priority dates do not protect the uses described in the change application so if the lease is revoked, they must procure water from a different source, which will have a new priority date. If they secure their own water right now, the right's priority date will ensure that no newly appropriated water rights can impair their use in the future and that priority date will stand until they no longer use the water. For these reasons, we recommend that Blue Castle Holdings, Inc. applies for its own water right.

5.5 References

[1] *Introduction to Blue Castle Holdings, Inc. and the Blue Castle Project ESP Application*, 1st ed. Blue Castle Holdings, Inc., 2015.

[2] "Utah Division of Water Rights," [Online]. Available: www.waterrights.utah.gov. [Accessed 21 April 2015].

[3] M. Stilson, Interviewee, *Price, Utah Regional Engineer - Division of Water Rights.* [Interview]. 20 April 2015.

[4] N. Rodriguez, "Blue Castle Gets Utah Water Rights for $18B Nuke Plant," Law 360, 20 January 2012. [Online]. Available: http://www.law360.com/articles/302050/blue-castle-gets-utah-water-rights-for-18b-nuke-plant . [Accessed 21 April 2015].

[5] Division of Water Rights, Water Rights Law Title 73, Salt Lake City, 2013.

[6] K. L. Jones, "Order of the State Engineer for Permanent Change Application Number 89-74 (a35402)," Division of Water Rights, Salt Lake City, 2012.

[7] Utah Department of Administrative Services Division of Administrative Rules, 'UT Admin Code R655-5. Maps Submitted to the Division of Water Rights.April 1, 2015', *Rules.utah.gov*, 2015. [Online]. Available: http://www.rules.utah.gov/publicat/code/r655/r655-005.htm#T3. [Accessed: 29- Apr- 2015].

Chapter 6

Water Resources: Supply and Effluent

Abstract
This research focused on the water transportation system to the proposed plant location. It was found the BCH plans to use a closed-loop cooling water system. We also determined the (possible) location of the water pipeline, outlined a design possibility for a pumping system to provide cooling water for the AP1000 reactor as a sample for determining project feasibility. We researched the quality of the Green River and how the plant will treat the water using a sedimentation pond and the Demineralized Water Treatment System. It was estimated that the plant will discharge approximately 5% of its cooling water, or 1.6 cfs. Topographic maps of the region surrounding the proposed location were evaluated for the most efficient path of water transport. The required flow rate for the plant was based on the AP1000 reactor specifications. The pumping system was designed based on required flow rate, elevation change, and maintenance requirements. Seasonal water qualities of the Green River were evaluated to analyze the sedimentation pond and Demineralized Water Treatment System. Discharge volume estimates were based on EPA guidelines for boiler design.

6.1 Introduction

Providing a reliable source of water to the plant is crucial for successful plant operation. This chapter analyzes the BCP water transportation system from the Green River to the proposed site. A pipeline, pumping system, sedimentation pond, and evaporation pond will comprise the major components of the water transportation system. The design parameters, analysis of data, final design proposals, and cost analysis are presented for each of the system constituents. The proposed site map according to the BCH Preliminary Research for Permit Application [1] was used for evaluation.

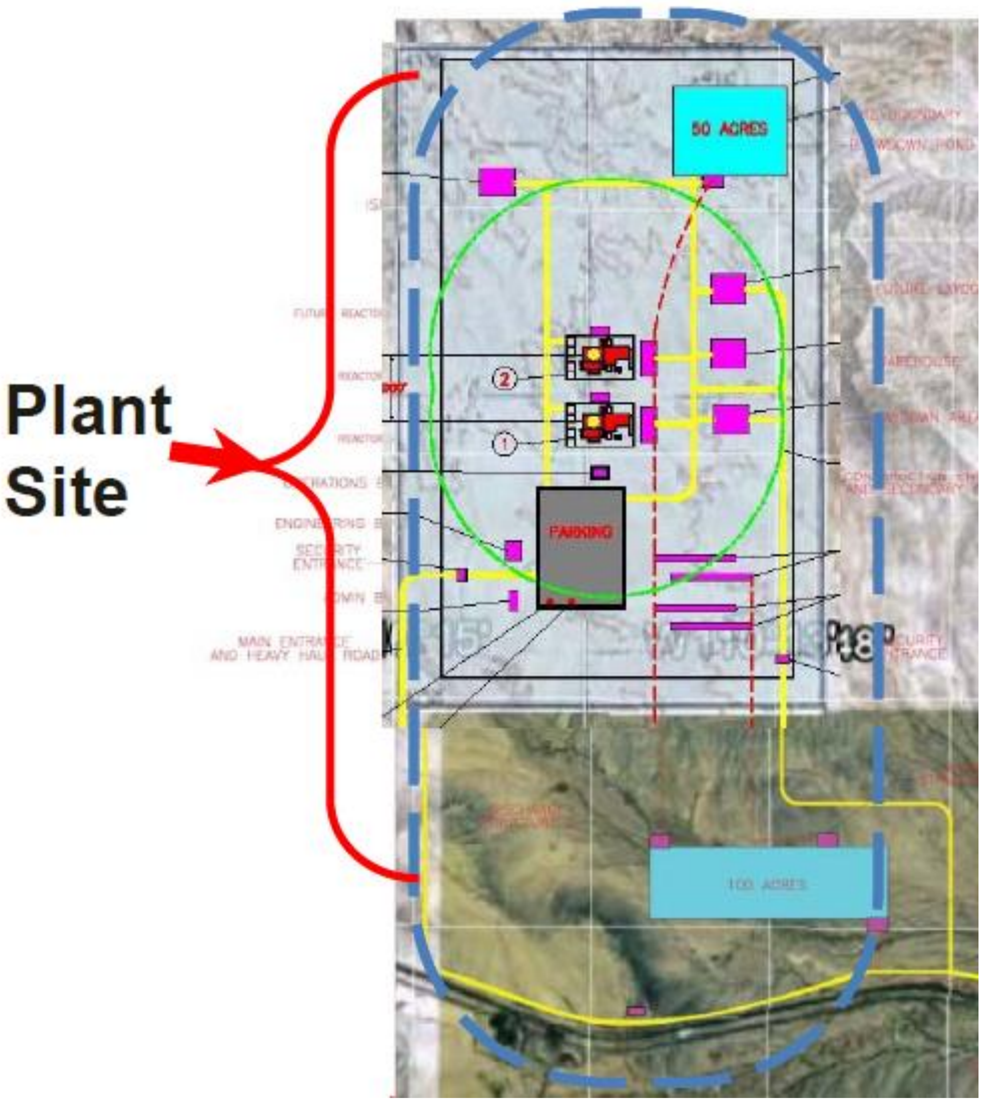


Figure 6.1: BCH Proposed Site Map.

6.2 AP1000 Reactor Water Requirements & Analysis Assumptions

The average AP Reactor Cooling System requires 16.02 cfs per reactor [2] , so the proposed plant will require 32.04 cfs to adequately cool both reactors. BCH is proposing a closed loop cooling system in which heated cooling water is cooled to approximately 89 degrees F by use of Mechanical Draft Cooling Towers then recycled through the condenser of the turbine loop [3]. Using a closed loop system such as this greatly reduces the required draw on the Green River compared to a once-through system. Though the proposed plant will not require the full water right secured, our proposed source water pump system design (used for analysis of project feasibility) utilizes the entire leased water right (74 cfs). This was done to consider pumping requirements at full operating potential.

According to the Nuclear Regulatory Commission, “Reactor coolant pressure boundary components are designed and fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section III. [3]” Therefore, we assume the required quality of the cooling water mimics that of a boiler system to avoid precipitate solid scales on surfaces and subsequent material failure and possible explosion. This assumption governs our “blowdown” calculations and evaporation pond analysis.

6.3 Sample Pump Design for Analysis

6.3.1 Pumping requirements

The distance from the Green River to the 100 acre sedimentation pond is roughly 4.4 miles. Over this distance there is a gain in elevation of roughly 140 feet. In order to move water from the river to the sedimentation pond, a series of pipes and pump houses was designed keeping in mind the variation of water demand at different times of year. These demands change due to ability to recirculate water from cooling towers/ponds. During hot summer months, a smaller portion of the used water will be able to be used again. During the cold winter months, water can be cooled efficiently and quickly, and be recirculated into the cooling line to be used again to cool the reactors. With this variability, the demand for water being pumped from the river changes drastically. In order to accommodate these changes in demand, twelve identical pipelines were designed, allowing the use of any combination of the twelve lines to increase or decrease the amount of water being pumped from the river while allowing the pumps to run at the designed operating point. This ensures that the pumps will either operate efficiently or not be needed at all.

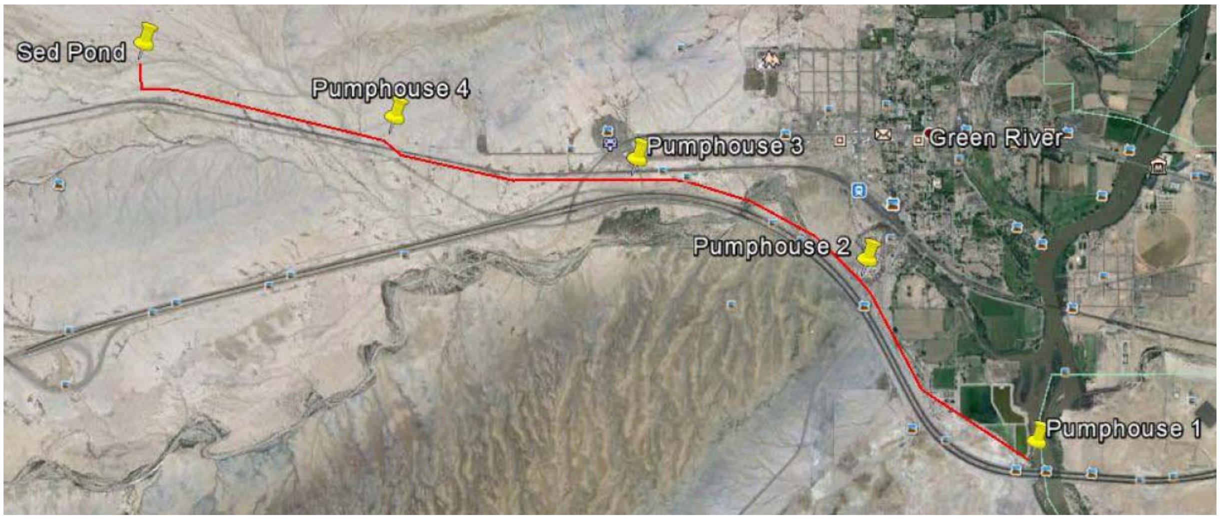


Figure 6.2: Map of Pipeline Route with Pump houses.

6.3.2 Pumping system specifications

Because the maximum water demand of the plant is 73 cubic feet per second (32,765 gallons per minute), it was determined that several pipelines would need to be utilized. In order to determine the pipe sizing, number of pipelines, and number of pumping stations, the total dynamic head calculations are shown in Appendix 6.1. Once the calculations were performed, a pipe route was determined and the route was divided into four sections of the same length, each requiring roughly the same amount of elevation gain. A map of the pipeline route with place marks at each pumping station is shown below.

Due to the possibility of freezing temperatures in the winter months, the pipeline is to be buried at a depth of 60 inches to keep it below the frost table [4].

Because the length of each section was the same, and the elevation gain was so similar, a single pump design was required to meet the needs of each similar section. It was decided to utilize twelve identical pipelines each using a Weinman 10L2-182 10x12x14 case pump to move the water along each section. The figure below shows the pump performance curve used to determine the operating point.

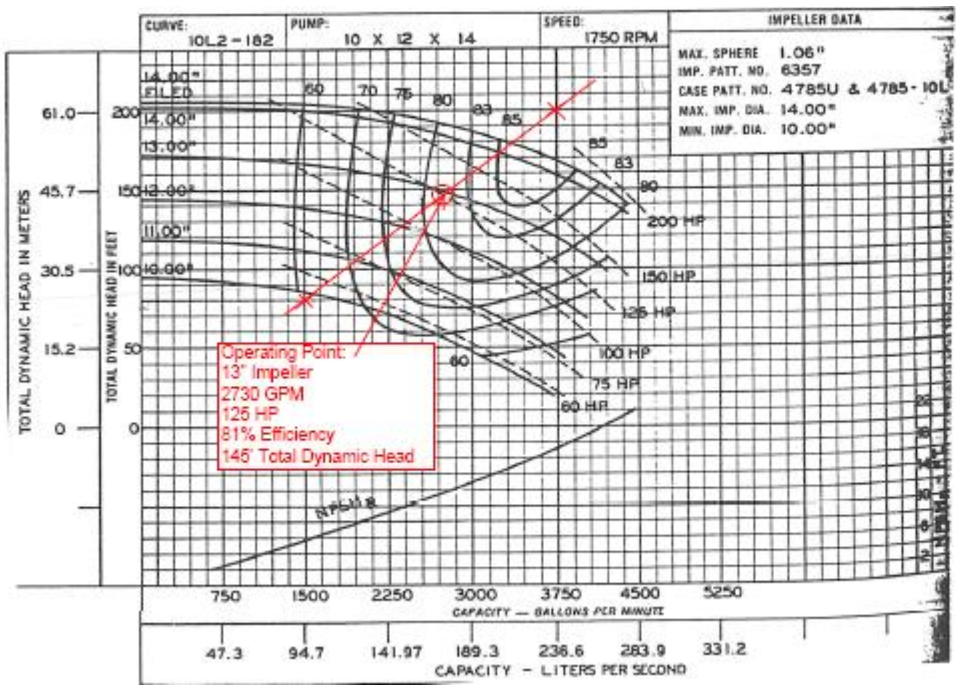


Figure 6.3: Weinman 10L2-182 Pump Performance Curve.

Because the designed operating point provides 2730 gallons per minute for each pump, if all twelve pumps operating at the same time a total of 32760 gallons per minute will be pumped from the river. This makes it impossible to ever surpass the allotted 32765 gallons per minute granted in the leased water rights.

6.3.3 Pump Maintenance

Monthly maintenance is to be performed on the pumps. This maintenance includes visual inspection, visual check for leaks, performance tests, lubrication of valves and moving parts, cleaning, etc. During the inspection and maintenance of each pump, it is to be powered off, leaving the remaining eleven pumps in full operation. It is anticipated that monthly maintenance will take two working days. This means that two days each month, the maximum operating capacity will be 91.7% while one pump line at a time is shut down. A table presenting the operating capacity as percentage based on number of pumps in operation is shown in Table 6.1.

Table 6.1: Operating Capacity.

Number of pumps	Flow rate (GPM)	Operating Capacity (%)
1	2730	8.3
2	5460	16.7
3	8190	25.0
4	10920	33.3
5	13650	41.7
6	16380	50.0
7	19110	58.3
8	21840	66.7
9	24570	75.0
10	27300	83.3
11	30030	91.7
12	32760	100.0

Major maintenance will need to be performed on an as-needed basis. During winter months when fewer pumps are needed, the pumps being used are to be rotated to keep usage hours nearly the same on each set of pumps. These changes should be made during scheduled monthly maintenance.

6.4 Green River Water Quality

The USGS conducted a water quality study of the Green River near Green River, Utah in 2005 [5] The water at the point where BCH plans to draw the plants source water had a high hardness of 270 mg/L CaCo3, alkalinty of 168 mg/L, and total dissolved solids (TDS) of 17.8 milliequivalents per liter. The Ion concentration of measured components as a percentage of TDS is shown in Table 6.2.

Table 6.2: Ion Concentration as Percent of Total Dissolved-Solids Concentration.

Calcium	Magnesium	Sodium	Potassium	Chloride	Fluoride	Bicarbonate	Sulfate
18	13	20	<1	4	<1	19	26

According to the same study, agricultural runoff upstream of the plant source water site contributes to the water hardness and alkalinity. Future agricultural growth in the region may increase these qualities if agricultural practices stay constant.

The Green River soil series (soil that covers watershed areas) [6] was evaluated and, the rain runoff into the Green River contains fine clay particles, fine sands, and very little silts. Fine sands are dense enough that they settle quickly in the river. Therefore, assuming water is pumped from a height far enough above the river bed to avoid collecting sedimentation particles, the remaining particles to be removed from the water will primarily be fine clays with very little fine silts and fine sands.

6.5 Sedimentation Pond

The proposed sedimentation pond is 100 acres and will be approximately 1 mile x 0.15 mile (scaled from Figure 6.1). The water will flow in directly from the pipelines at one input location. Fine sands have settling velocities between 0.042 and 0.100 feet per second, meaning they will settle about 10 feet in approximately 1.5 - 4 minutes. Assuming fine clay particles have a grain size diameter of 997 nm, according to Stokes law, the settling velocity is approximately 9.94009 x 10-13 m/s, or essentially, 0. This means that the clay particles will not settle as is. This indicates that the water will likely undergo some form of treatment at this stage to cause the clay particles to flocculate/coagulate and increase settling velocity. Typical methods for encouraging coagulation are the addition of Aluminum Sulfate also called Alum ($Al2(SO4)2$) or Ferric Sulfate ($Fe2 (SO4)3$). Bentonite clay is utilized as a coagulant aid in conjunction with a primary coagulant (such as Alum or Ferric Sulfate) in some applications [7] so the particles in the clay will bond quickly and the coagulant treatment methods will be very effective. In addition, the alkalinity of the water is high enough that it is suitable for Alum or Ferric Sulfate driven coagulation [7].

In addition to serving as a sedimentation pond, it is likely that the pond is a precautionary measure against prolonged power-outage or system malfunction. The Palo Verde Nuclear Generating Station located in downtown Phoenix has more than "4.4 billion gallons of water stored on site to provide sufficient cooling water for longer than one year in the unlikely event of a severe accident [8]."The depth of the proposed BCH sedimentation pond is not known, but if we assume a depth of 10 feet, the one acre pond could provide roughly 435,000 cubic feet or 3.25 million gallons of water (neglecting evaporation) in the event of a catastrophe.

The Evaporation rate for the region ranges from 40 to 44.6 inches per year and the average rainfall is about 4 inches per year [6]. That means that up to 162,000 cubic feet will evaporate per year and 14,500 cubic feet will be replenished by rainfall. This leaves a net deficit of 147,500 cubic feet per year, or 0.00467cfs. This amount is so small that it is almost negligible when considering the water rights procured and the reactor cooling water needs.

Blue Castle has not specified their methods for ensuring proper settling, however, maintenance of the pond will likely involve balancing of chemicals for coagulation due to the nature of the water being treated. Any excess unsettled solids or excess additives would create more material to be treated prior to entering the cooling system and therefore should be avoided. The addition of a coagulant would increase the volume of solids that would settle in the basin. Dredging may be required to maintain an acceptable depth, however the settled solids are non toxic and should not have any significant environmental impact or require significant monetary investment.

6.6 Dissolved Solids Treatment

Prior to entering the reactor cooling system, the water needs to be treated to avoid damage to the mechanical system.[3] Water will be pumped from the sedimentation pond to the Demineralized Water Treatment System. This system processes the water to remove ionic impurities (those listed in Table 6.2). It consists of four major processes : filtering of remaining fine particulates (such as silts that could not be settled with coagulation methods) , two reverse osmosis feed pumps, two 100 % reverse osmosis units in series, and one electrodeionization unit for secondary demineralization [6]. From here, water can enter the cooling system for use. Water is continually treated within the cooling system as well. With heated temperatures and high oxidation, water can begin to oxidize the system; breaking down materials resulting in suspended and dissolved solids in the water. In boiler systems, deoxygenation of water is mandatory to prevent such degradation and possible system failure, however it is systematically unfeasible in a closed loop nuclear power plant such as the proposed BCH plant. Alternatively, the heat transfer surface (where oxygenation primarily takes place) is made of Titanium, an extremely heat and rust (oxygenation) resistant material [6]. Consequently, plant efficiency is maintained with little to no scrubbing. Blowdown is well oxygenated and consists mostly of breakdown from other system components, grease, and dissolved solids that were not entirely cleaned in the preliminary water treatment.

6.7 Wastewater

6.7.1 Waste Water Quality

The AP1000 nuclear reactors proposed for use at the Green River, Utah site are a closed loop system that require less water than a plant with a direct or once through cooling system design. In a closed-cycle cooling system, a small fraction of the condenser circulating water is continuously lost by evaporation and drift in the cooling tower. In this process, "to control the concentrations of additives and natural minerals in the water, a small portion of the condenser circulating water must be continuously removed and replaced with fresh water supplied by the plant intake pumping station [9]."

The closed loop system loses approximately 3%-5% water to evaporation. The remaining water is recirculated in the system. The 5% loss due to evaporation and "blowdown" is replenished with fresh water and the cycle is continued.

"The cooling water would be reused until the total dissolved solids concentration in the circulating water would become unacceptable." The unacceptable water is known as blowdown. The blowdown from the circulating cooling water is then piped to an onsite closed evaporation basin [10].

6.7.2 Evaporation Pond Design

The waste water or "blowdown" from the cooling process is transported through a series of pipes and is delivered to a closed system evaporation pond. The closed system is an input only design, this ensures that there will not be any discharge of waste water returned to the Green River [3].The evaporation pond design will require an impermeable barrier for the BCP site. A 2-5 foot layer of compacted bentonite clay will be used as the liner. The compacted clay liner should have a maximum hydraulic conductivity of 4x10^-8. Hydraulic conductivity refers to the degree of ease that fluid can flow through a material [11].

The process for constructing the liner for the evaporation pond is as follows, "bentonite is spread over the soil at the specified application rate and then the bentonite/soil combination is uniformly mixed using large scrapers, dozers and discs to efficiently mix the soil, once the soil/bentonite mixture reaches the correct ratios the mixture is hydrated to +- 2% of optimum moisture content and then compacted. Compaction is necessary to reduce the voids in the soil, and help the clay particles lay flatter together. Compaction is usually done with a sheepsfoot vibratory compactor in combination with other heavy equipment onsite [12]. It is very important that no more than 6" layers or lifts be constructed at a time, the reason for the 6'' lifts are to reduce the possibility of creating a void and to ensure proper compaction and construction of the liner.

The sides of the evaporation pond are to be constructed with a 3:1 slope, this is done as a safety measure to provide an emergency egress due to unintentional pond entry. Pond depth will be determined based upon cooling water blowdown flow rates and evaporation rates for this area. Information regarding the waste water flow rates specific to the Green River proposed plant have been difficult to procure. Westinghouse has stated that the design of the wastewater retention basin is a site specific matter and has not provided any detailed information [13].

Due to the lack of information regarding these rates, suppositions have been made regarding pond design. The evaporation pond is required to support and store the volume of wastewater being discharged during months that evaporation rates are low (Nov-Apr). During these months there will be little or no evaporation occurring, however; during this time period there will be precipitation accumulation that will occur, the pond design will need to account for storing this water in addition to the normal volume of waste water. The evaporation rates in the area of Green River, UT are 40-44.6 inches per year on average, with the highest evaporation rates occurring from March to October. With this information the evaporation rates of a 50 acre or approximately 2.2 million square foot pond will be 7.2-8.1 million cubic feet per year. There will be no annual accumulation of waste water in the pond so the flow rate of waste water into the pond cannot exceed the evaporation rates annually. Based on this information, a pond design with a 10’ depth should be sufficient to handle any volume of water accumulated during months with low evaporation rates.

6.8 Conclusion

The sample pumping system designed from standard methods concluded that pumping the water from the Green River to the plant is feasible and cost effective. The closed loop cooling system of the proposed plant is an efficient use of water, greatly reducing the water demand for operation compared to a once-through system. This enables the plant to easily store up water as a security measure in a sedimentation pond for use following a catastrophe. Also, because the water demand is much less than the reserved water right, the plant will be able to continue operation in the event that BCH’s water rights are reduced. The evaporation pond will hold blowdown from the cooling water system. This blowdown is composed of metals, greases, and oils picked up from the cooling path and cooling towers. The blowdown is not radioactive, however it may contain toxic materials. The sedimentation pond will be lined with compacted clay to prevent contaminates from leaching into the groundwater.

6.9 References

[1] Blue Castle Holdings, "An Introduction to Blue Castle Holdings and the Blue Castle Project ESP Application," BCH, Provo, 2011.

[2] D. o. N. R. L. O. o. N. R. Regulation, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Plant Design Docket No. 52-006," U.S. Nuclear Regulatory Commission, Washington DC.

[3] N. R. Commission, "AP1000 Design Control Document," Nuclear Regulatory Commission, Rockville, 2011.

[4] F. H. Administration, US Department of Transportation.

[5] U. G. Survey, "Hydrology and Water Quality in the Green River and Surrounding Agricultural Areas near Green River in Emery and Grand Counties," USGS, Salt Lake City, 2005.

[6] U. G. Survey, "Green River Series," USGS, Salt Lake City, 2011.

[7] M. E. C. College, "Coagulation and Flocculation," MECC, Big Stone Gap.

[8] e. a. C. Eichelberger, "The Solution for Managing Nuclear Power Generation Water Supply in an Arid Environment," Industrial Fabrics Association International, Roseville, 2013.

[9] T. V. Authority, "Single Nuclear Unit at the Bellefonte Plant Site," Tennessee Valley Authority, Jackson, 2010.

[10] R. Whited, "Pre-Application Readiness Assessment Visis for an Early Site Permit at the Blue Castle Project Site," Division of Site and Environmental Assessment, 2011.

[11] EPA, "Protecting Ground Water: Technical Considerations for New Surface Impoundments, Landfills, and Waste Piles," EPA.

[12] Bentoniteliner.con, "Uses of Bentonite," bentoniteliner.com.

[13] EPA, "Generic Design Assessment: AP1000 nuclear power plant design by Westinghouse Electric Company LLC," Environment Agency, Bristol, 2011.

Appendix 6.1: Hydraulic Head Calculations

Equations used:

$$\frac{P_1}{\gamma_{water}} + z_1 + \frac{{v_1}^2}{2g} + h_A - h_L = \frac{P_2}{\gamma_{water}} + z_2 + \frac{{v_2}^2}{2g}$$

$$h_L = L[\frac{Q}{0.285 * c_h * D^{2.63}}]^{1.852}$$

$$h_{L_{minor}} = K * \frac{Q^2 * \left(\frac{1}{449}\right)^2}{2gA}$$

$$h_A = \frac{P_1 + P_2}{\gamma_{water}} + (z_2 - z_1) + \left(\frac{{v_2}^2 - {v_1}^2}{2g}\right) + h_L + h_{L_{minor}}$$

$$h_{L_{total}} = h_L + h_{L_{minor}}$$

$$v = \frac{Q}{A}$$

Discharge Line 1:

$$h_L = 5770ft[\frac{2760gpm}{0.285 * 140 * 10^{2.63}}]^{1.852} = 81.72ft$$

$$h_{L_{minor}} = 0.112 * \frac{2760^2 * \left(\frac{1}{449}\right)^2}{2 * 32\frac{ft}{s^2} * 0.545415} = 0.221ft$$

$$h_A = \frac{0 + 0}{62.4pcf} + (4115ft - 4080ft) + \left(\frac{\frac{11.27ft}{s}^2 - \frac{4.08ft}{s}^2}{2 * 32\frac{ft}{s^2}}\right) + 81.72ft + 0.221ft$$
$$= 118.67ft$$

Discharge Line 2:

$$h_L = 5770ft[\frac{2760gpm}{0.285 * 140 * 10^{2.63}}]^{1.852} = 81.72ft$$

$$h_{L_{minor}} = 0.112 * \frac{2760^2 * \left(\frac{1}{449}\right)^2}{2 * 32\frac{ft}{s^2} * 0.545415} = 0.221ft$$

$$h_A = \frac{0 + 0}{62.4pcf} + (4150ft - 4115ft) + \left(\frac{\frac{11.27ft}{s}^2 - \frac{4.08ft}{s}^2}{2 * 32\frac{ft}{s^2}}\right) + 81.72ft + 0.221ft$$
$$= 118.67ft$$

Discharge Line 3:

$$h_L = 5770ft[\frac{2760gpm}{0.285 * 140 * 10^{2.63}}]^{1.852} = 81.72ft$$

$$h_{L_{minor}} = 0.112 * \frac{2760^2 * \left(\frac{1}{449}\right)^2}{2 * 32\frac{ft}{s^2} * 0.545415} = 0.221ft$$

$$h_A = \frac{0+0}{62.4pcf} + (4185ft - 4150ft) + \left(\frac{\frac{11.27ft}{s}^2 - \frac{4.08ft}{s}^2}{2 * 32\frac{ft}{s^2}}\right) + 81.72ft + 0.221ft$$
$$= 118.67ft$$

Discharge Line 4:

$$h_L = 5770ft[\frac{2760gpm}{0.285 * 140 * 10^{2.63}}]^{1.852} = 81.72ft$$

$$h_{L_{minor}} = 0.112 * \frac{2760^2 * \left(\frac{1}{449}\right)^2}{2 * 32\frac{ft}{s^2} * 0.545415} = 0.221ft$$

$$h_A = \frac{0+0}{62.4pcf} + (4220ft - 4185ft) + \left(\frac{\frac{11.27ft}{s}^2 - \frac{4.08ft}{s}^2}{2 * 32\frac{ft}{s^2}}\right) + 81.72ft + 0.221ft$$
$$= 118.67ft$$

[Applied Fluid Mechanics, Robert L Mott, 6th edition chapter 7]

Chapter 7

Environmental Impacts: Ecology, Air, and Water

Abstract
Conservation and preservation of the natural environment is key to the sustainability of Southwestern Utah. Because the Green River is the major tributary of the Colorado River, it not only supports local Utah communities, but is also an important supplier of water for most of the southwest United States. Due to the significance of the Green River, any new development may result in a significant impact on flora and fauna in and around the river.

Because the Blue Castle Project (BCP) is near the Green River, withdraws water for cooling, and requires a pipeline to transport that water, a study must be completed in order to determine if the BCP will be sustainable for future use. The study will mainly focus on the impacts that the BCP will have on the river and related flora and fauna. This chapter will cover 1) the current ecology of this section of the river, 2) the short and long term effects that construction and operation will have on the local air as well as the global climate, 3) the potential impacts the facility will have on the water in the Green River, and 4) the environmental impact of nuclear exposure.

Exploratory research of other completed nuclear plants has shown that there can be very little environmental impact from the operation of a nuclear power facility. More thorough research is done in this report into the specifics of the BCP, such as the impacts on endangered species and water availability for communities reliant on the Green River. Finally, a recommendation is issued regarding the feasibility of the facility based solely on its environmental impact.

7.1 Introduction

Technological and educational advances have provided the ability to study the effects of an engineering project on the environment. Environmental impact is one of the most important factors in the design of a large-scale project, such as the Blue Castle Project. The Blue Castle Project can affect several environmental aspects, but the central discussed components are the construction and operation of the nuclear plant on the local ecosystems, air and water. Habitat disruption is possible along with several other negative impacts including pollution of water supply. Finally, the environmental impacts of a nuclear incident are discussed.

7.2 Green River Ecology

The Green River, beginning in the Wind River Mountains of Wyoming, flows over 700 miles to its confluence in Canyonlands National Park with the Colorado River. One major dam, the Flaming Gorge Dam, obstructs the Green River. This dam creates the Flaming Gorge Reservoir and a tailwater river, which flows out of the dam and continues to Canyonlands National Park. The Green River is world renowned for fly-fishing due to the bustling local river ecology. The river holds 15,000 trout per mile and has one of the highest densities of floating biomass of any river in the United States. The ecology of the Green River thrives as a result of the water released from Flaming Gorge Dam. The river consistently obtains water temperatures and flow rates ideal for ecological growth. Keeping the river ecology in best conditions requires a balance between fishery biologists, and the farmers and communities down river from the dam that are reliant on the river.

7.2.1 Flora

One of the few sources of water in Southwestern Utah, the Green River has a dominant riparian plant community. Since the Green River flows through various ecosystems before it enters the desert, focus will be placed on the desert ecosystem of which the Green River supports. The flora that the Green River supports can be divided into two distinct sections: the Riparian green belt, adjacent to the river, and the surrounding desert flora. Cottonwoods, tamarisk and willows are the most predominant members of this riparian zone [2].

Figure 7.1: Green River Below Green River, UT [3].

The riparian zone harshly contrasts the desert surrounding it as seen in the figure above. The plant community relies mostly on river water for its sustenance, as rainfall is limited to 7.11 inches per year [4].

Several plant species are housed in the desert area surrounding the Green River. The most common plants are shadscale, sagebrush, cactus as well as other desert shrubs [2]. Cryptobiotic soil, a desert shrub, is a delicate layer of plant life over the soil. It is made up of lichen and protects the otherwise unstable land from erosion [5].

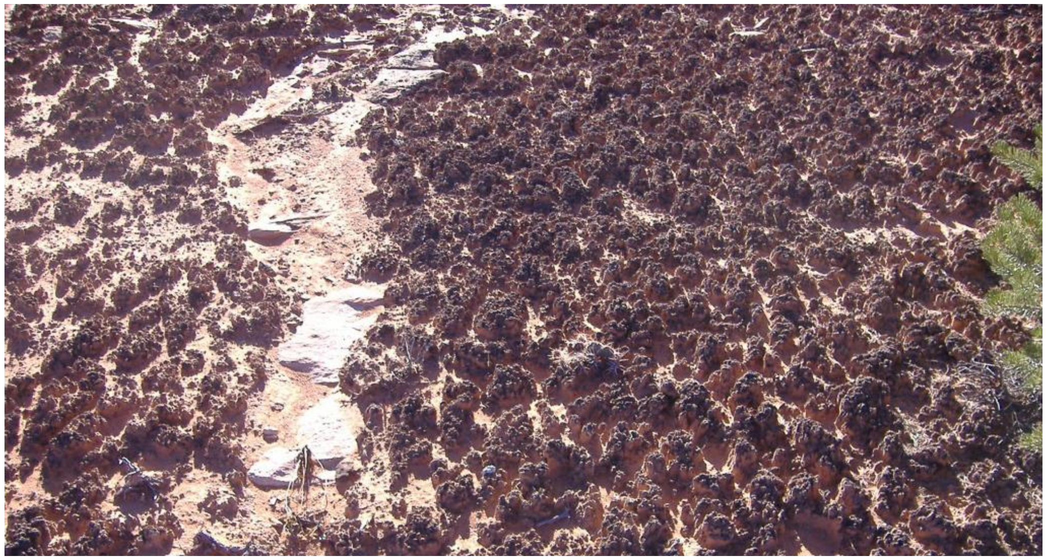


Figure 7.2: Cryptobiotic Soil [6].

These plants are accustomed to a desert ecosystem and rely on limited water and natural water storage for their sustainability.

7.2.2 Fauna

The riparian habitat of the Green River supports a large animal population. The fauna are divided into the animal life surrounding the river and the animal life within the river. Animal life outside of the river consists of lizards, toads and other small animals. Arachnids, amphibians, coyotes and deer are also found around the Green River. In addition to land animals, a large amount of birds are native to the Green River. Local birds include waterfowl, Golden Eagles, Pinyon Jays, Kingbirds, Peregrine Falcons and sparrows [7]. Migrating birds also visit the Green River as it is a key north to south flyway. The northern section of the Green River contains a variety of fish species. Up to 15,000 trout per mile inhabit the water stream [8]. The southern portion of the Green River Colorado is comprised of Pikeminnow, Razorback Sucker, Humpback Chub, and Bonytail Chub [9].

7.2.3 Effects of Proposed Nuclear Plant on Local Ecosystems

The impact on the flora and fauna at the proposed site is paramount because they are the main inhabitants of the area.

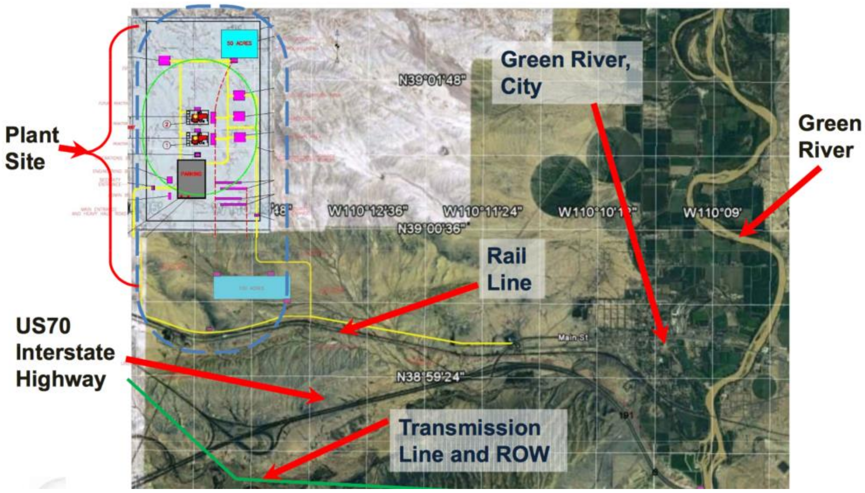


Figure 7.3: Blue Castle Proposed Site [10].

7.2.3a Effects on Flora

The proposed power plant site is 5 miles away from the city of Green River, UT. The distance prevents major impact to the riparian zone surrounding the river, as the flora do not rely on river water. The water draw down leased for the plant is 74 cfs, which is 1.2% of the Green River's average flow, therefore the absence of water will not impact the river's riparian zone [11].

7.2.3b Effects on Fauna

The 1.2% withdrawal of water will not have a negative impact on the river environment or fish. The Endangered Species Act of 1973 prevents endangered species such as the Colorado Pikeminnow, from extinction due to human alteration [9]. Because of this requirement, the intake pipe will have a screen and an intake velocity of .33 ft/s, which is below the EPA required .5 ft/s [12]. The water withdrawal will have minimal effect on the river ecosystem.

The next area of concern is effect on the fauna that currently inhabit the proposed construction site. As these animals are not in the riparian zone and do not rely on river water, they can freely migrate into adjacent habitats. The plant is located far enough away from the river to have a marginal influence.

7.2.3c Construction Impacts

The operation of the plant will have a small effect on the local flora and fauna. A pipeline, to transport the water, needs to be built. The pipeline will pass through the riparian area surrounding the river causing a temporary disturbance to local wildlife and plant life. Once the pipeline is in place, the impact will decrease while the local ecosystem adapts to it. The construction of the plant site will also have an impact on the wildlife. The local wildlife will need to be relocated. The plant life in the project area will also be destroyed in the construction process. Because the proposed site for the nuclear plant is in the Utah desert, there is much less effect on living organisms as there are simply less living organisms in the desert.

7.3 Impacts on Air and Climate

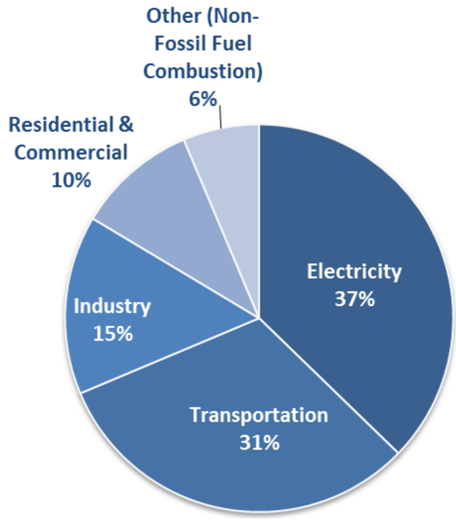
The airborne impacts of the facility are to be examined on both a micro and macro scale. The effects of the plant's operation will be discussed, as well as effects of the facilities construction. Additionally, long term and short term effects will be examined.

7.3.1 Power Plant Emissions

Changes in the local climate such as the addition of harmful materials or an abrupt alteration in the chemical composition of the air have the potential to be catastrophic to the life forms in the area. These changes are harmful to humans as well. Workers at the facility and the inhabitants of Green River, Utah are at the most risk. The Clean Air Act was passed by the federal government in 1970 to set the goal of protecting public health and welfare by establishing limits on the emissions of hazardous air pollutants [13]. All nuclear power plants must comply with the regulations and requirements enforced by the act. The act sets strict limitations on the amount of nitrogen oxide, sulfur dioxide, particulate matter, and mercury emitted from energy production. Nitrogen dioxide is "a precursor of ground-level ozone and smog," while sulfur dioxide "produces acid rain" [14]. Heavy particulate matter like smoke and dust interferes with the respiratory system of animals and humans. Mercury is toxic in high levels. Nuclear reactors create heat from fission, not combustion of fuel, and therefore do not create any of the harmful pollutants discussed. The amount of nitrogen oxide nuclear power plants prevent is equivalent to taking over 28 million cars off the road annually [14]. In fact, the white smoke created by the cooling towers is steam – harmless water vapor.

7.3.2 Effect on Climate

Since the Industrial Revolution, humans have been discharging carbon dioxide (CO_2) into the atmosphere at increasingly high rates. Figure 7.4 shows that the main source of CO_2 emissions in the U.S. is electricity generation, which is due to the burning of natural gas, coal, and petroleum [15]. The burning of fossil fuels accounts for around 67% of the nation's electricity, while nuclear power only accounts for 19% [16]. Nuclear power plants do not emit any CO_2 during operation [14]. In 2004, CO_2 reductions in the electric power sector were over 282 million metric tons. The majority of this is attributed to improvements and increased generation at existing nuclear power plants, as seen in Figure 7.5. "Since 1980, the carbon intensity of electric power production—or the amount of carbon dioxide (CO_2) emissions per kilowatt-hour of electricity—has decreased by 10%. This decrease in carbon intensity was accomplished by increased generation efficiency and capacity improvements at coal and nuclear power plants" [17]. At the same time, "If atmospheric carbon dioxide concentrations increase from current levels near 385 parts per million by volume (ppmv) to a peak of 450–600 ppmv… the coming century… [will see] irreversible dry-season rainfall reductions in several regions comparable to those of the 'dust bowl' era and inexorable sea level rise" [18].



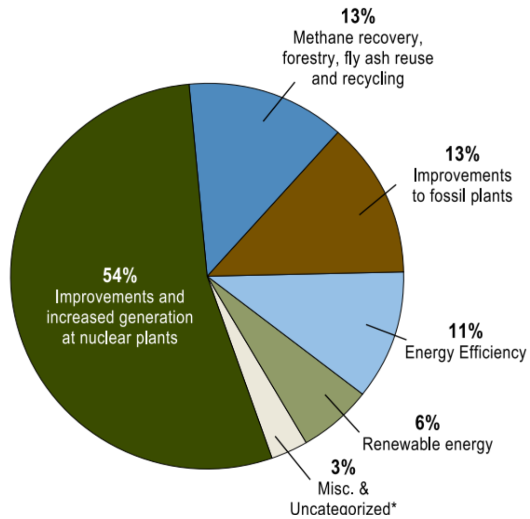


Figure 7.4: U.S. Carbon Dioxide Emissions by Source

Figure 7.5: Electric Power Greenhouse Reductions by Project Type [17].

Because nuclear power production is carbon neutral, it does not contribute to destructive global climate change. Increased usage of nuclear power reduces reliance on fossil fuels for electricity, which simultaneously slows the rate of climate change from CO_2 emissions.

7.3.2a Emissions due to Construction

While operation of the proposed plant will not produce any harmful air pollutants, the construction will yield emissions from the burning of fossil fuels. The Blue Castle Project is designed similarly to Plant Vogtle, and will likely require a comparable completion time of 11 years. During this multi-year period, cranes, bulldozers, and trucks will be operating and burning diesel for fuel, producing carbon dioxide, nitrogen oxide, and sulfur dioxide; all of which are harmful gases. The presence of these chemicals will contribute to climate change and global warming on a worldwide scale.

7.4 Water

Water is a primary component in the generation of nuclear energy. It is used in the withdrawal and consumption process. Water is consumed when it is evaporated in the cooling process [19]. More importantly, it is used for producing electricity, maintaining the system, and processing fuel in the nuclear power cycle. The nuclear power plant of the Blue Castle Project will be a pressurized AP 1000 reactor that will use a recirculating cooling system [20]. “[The system] boils water to make steam, outside the reactor… [which] must be cooled after it runs through a turbine to produce electricity” [20]. Water is required for the processing, mining, milling, and enrichment of the fuel. [20]. Finally, “the proposed Blue Castle Project would increase the electricity generated in Utah by approximately 50%, adding about 3,000 megawatts of installed electrical capacity, using less than 1% of Utah's current water diversion, and with a very favorable state-wide economic impact”[21].

7.4.1 Water Quality

Using water to benefit the energy process harms the water. Nuclear power plants have the possibility of exposing the river source to water discharges, water runoff, and radioactive waste. This exposure reduces water quality and delivers pollution to water, as groundwater and surface water are at risk. The Green River is tainted with sulfate, calcium, magnesium, and sodium bicarbonate [22]. “The concentration of dissolved solids (measured from specific-conductance measurements) in the Green River, major canals, and drains range from 192 to 5,910 mg/L” [22]. In addition, irrigation near the river has caused a concentration of dissolved solids “exceeding 1,000 ml/L” [22]. The overall water quality of the Green River near the town of Green River, Utah is mediocre.

7.4.2 Water Pollution

Contaminating agents that are able to pollute water are introduced by construction, water discharges, water runoff, and radioactive waste.

7.4.2a Construction

Nuclear power plant construction poses a threat to water quality. Equipment used to clear necessary land and to bring modules to the site are dangerous. Most commonly used, construction cranes operate using diesel-powered motors. Gasoline emissions from these cranes include, nitrogen oxides, hydrocarbons, carbon monoxides, sulfur dioxides, and nitrous oxides [23]. During construction, emissions enter the water stream and intensify contamination.

Figure 7.6: Construction Cranes at the Shimane Nuclear Power Station [24].

7.4.2b Water Discharges

Heavy metals and salts are used in the fuel, moderator, and coolant components of a nuclear power plant. These contaminants build up in the plant system and are transferred by the water. As the water escapes the system, the contaminants, too, escape. The water discharge location is exposed to these contaminants and becomes polluted.

7.4.2c Water Runoff

The runoff of nuclear waste in the water supply is a concern. “Although the nuclear reactor is radioactive, the water discharged from the power plant is not considered radioactive because it never comes in contact with radioactive materials. However, waste generated from uranium mining operations and rainwater runoff can contaminate groundwater and surface water resources with heavy metals and traces of radioactive uranium”[25].

7.4.2d Radioactive Waste

Several forms of radioactive waste are expelled from nuclear power plants. “High-level waste is primarily spent fuel removed from reactors after producing electricity…while low-level waste comes from reactor operations...[26]”. The fission process, used for energy generation, creates “fission products” from radioactive isotopes, which “account for most of the heat and penetrating radiation in high level waste”[26]. Low-level waste includes equipment and tools. These wastes are “typically stored on-site…either until it has decayed away and can be disposed of as ordinary trash, or until amounts are large enough for shipment to a low-level waste disposal site in approved containers” [26]. Exposures to either waste are harmful to water.

7.4.3 Mitigation Strategies

Water from the nuclear power plant system attains high temperatures and low oxygen levels. For these reasons, mitigation strategies must be considered for the Blue Castle Project.

7.4.3a Evaporation Pond

The problem of water discharges will be solved using an on-site 50-acre evaporation pond. “Blowdown from the circulating cooling water with high total dissolved solids would then be piped to an onside closed evaporation basin. There will be no discharge of blowdown to the Green River” [27]. 0% of water extracted for energy generation will be returned to the river therefore, contaminants will not enter the stream.

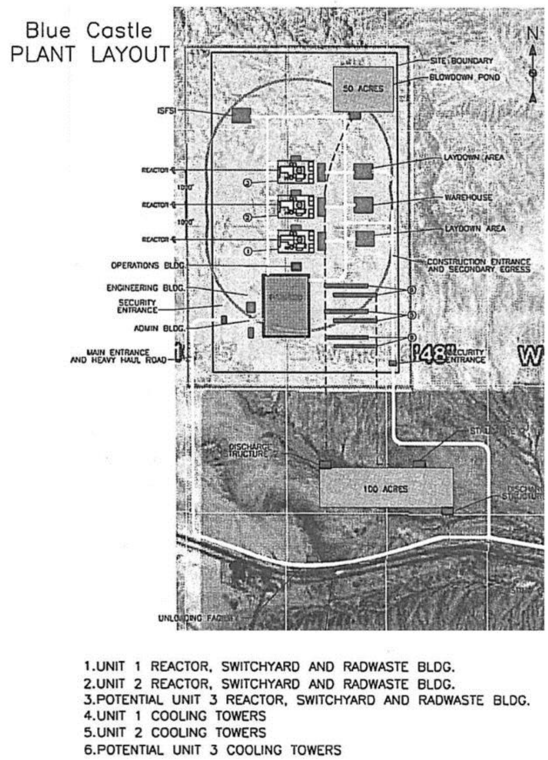


Figure 7.7: Blue Castle Plant Layout [28].

7.4.3b Containment Structure

Rainwater will not have access to radioactive materials, as the entire electricity generation process will take place in a containment structure [29]. The AP 1000 nuclear power plant will be both pressurized and protected to ensure that no radioactive discharges leave the system.

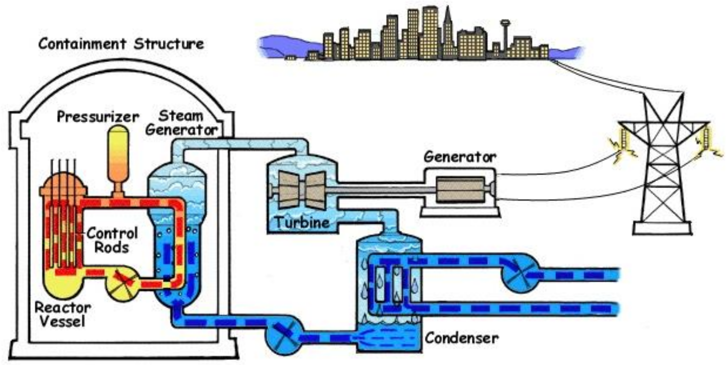


Figure 7.8: Nuclear Power Plant Contaminant Structure [29].

7.4.3c Spent Fuel Storage

On-site storage will prevent radioactive waste from entering the water stream. "Spent fuel will remain covered with water sources located in the spent fuel building for at least 3 days. Following [this time], water is provided by the ancillary storage tank" in a "5' thick, heavily reinforced concrete lined with steel" [30].

Figure 7.9: Spent Fuel Storage [26].

7.5 Impacts of a Nuclear Disaster

Nuclear meltdown occurs when the reactor cooling system or control rods fail, allowing continuous fission and heat production in the fuel rods. This creates temperatures high enough to melt through the facility, and release radioactive material to the outside environment.

7.5.1 Effects on Ecology

A radiation spill would not only affect the local wildlife, but the wildlife of the Southwestern United States. The river water carrying the spill contaminates land and water in Utah, Nevada, Arizona, and California. Radioactive contamination of groundwater is possible because the riverbed is not an impermeable membrane. Contaminated water cannot sustain life, therefore, uncontaminated water must be transported to the area creating cost and sustainability problems.

7.5.2 Effects on Air

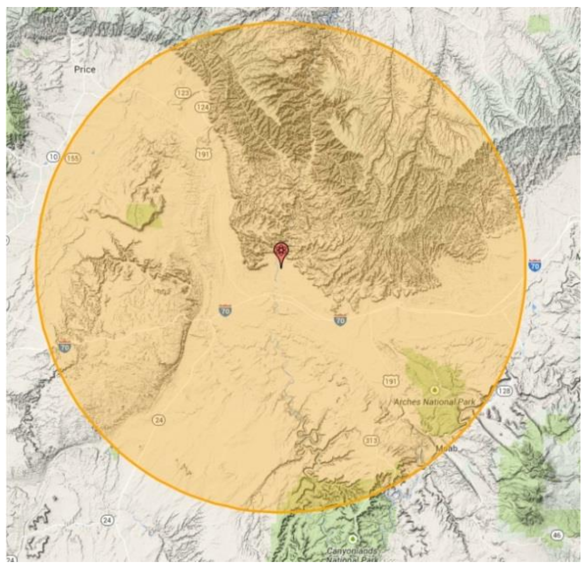


Figure 7.10: 50 mile radius around Blue Castle Project.

Nuclear reactors hold a relatively large amount of enriched uranium as fuel. A spill has the capacity for an area will become uninhabitable by humans for several years (e.g. Chernobyl). The U.S. federal government defines a 10 mile radius evacuation zone, and a 50 mile zone with a high potential for land contamination in the case of a severe nuclear incident [31]. Inside the evacuation zone, radiation levels are high enough to cause harm to humans from direct exposure. At the wider zone, contamination occurs in water supplies, food crops, and livestock from radioactive fallout [32]. At the Blue Castle Project site, a 10 mile radius encompasses the town of Green River, Utah. A 50 mile radius reaches both Canyonlands National Park and Arches National Park, and covers a large portion of Emery County, where 11,000 people that reside there [32].

7.5.3 Effects on Water

In the event of a nuclear disaster, both the water, and the aspects depending on water will suffer. Previous nuclear disasters such as Fukushima, Sellafield, Erwin, Braidwood, and Paks released radioactive materials, leaked uranium solution and spilled fuel pellets in water [33]. Contaminated river water leads to contaminated groundwater and drinking water. Those who ingest it are at risk of radioactive exposure. Nuclear disaster will pollute the water of the Green River and will affect water-dependent organisms.

7.6 Conclusion

The Green River can provide both energy for the Blue Castle Project and a home to flora and fauna. It contains ideal temperatures and flow rates that sustain ecological growth. Flora and fauna outside of the riparian zone are accustomed to desert climates, and do not rely heavily on an abundance of water. Therefore, absence of water will not impact their intake. Their habitats, however, will be disturbed, as relocation is necessary. Climate change resulting from equipment emissions is harmful to life forms. Fortunately, the Clean Air Act prevents extensive pollution. The majority of CO_2 emissions in the U.S. do not come from nuclear power but rather through burning of natural gas (diesel-operated construction). Next, water is used for withdrawal and consumption in the energy generation process. It is tainted with chemicals and dissolved solids and can be polluted through construction, water discharges, water runoff, and radioactive waste. Each contamination problem can be mitigated with an evaporation pond, containment structure, and spent fuel storage. In the event of a nuclear disaster, groundwater would not be able to sustain life, create uninhabitable areas, and hinder organisms that are dependent upon water. These facts showcase that the Blue Castle Project will have a miniscule environmental impact under normal operation, therefore the project can safely begin.

7.7 References

[1] Utah Chapter Sierra Club, 'Blue Castle-Green River Nuclear Power Plant', 2012. [Online]. Available: https://utah.sierraclub.org/content/blue-castle-green-river-nuclear-power-plant. [Accessed: 27- Apr- 2015].

[2] R. Webb, 'Green River', *Historytogo.utah.gov*, 2015. [Online]. Available: http://historytogo.utah.gov/utah_chapters/the_land/greenriver.html. [Accessed: 26- Apr- 2015].

[3] Google Earth, 'Green River, 2015. [Accessed: 26- Apr- 2015].

[4] Usclimatedata.com, 'Climate Green River - Utah and Weather averages Green River', 2015. [Online]. Available: http://www.usclimatedata.com/climate/green-river/utah/united-states/usut0094. [Accessed: 24- Apr- 2015].

[5] J. Belnap, 'Cryptobiotic Soils: Holding the Place in Place', *Geochange.er.usgs.gov*, 2015. [Online]. Available: http://geochange.er.usgs.gov/sw/impacts/biology/crypto/. [Accessed: 23- Apr- 2015].

[6] Roadhaus.com, 'Cryptobiotic Soil', 2014. [Online]. Available: http://www.roadhaus.com/images/Archy%20Campout/Cryptobiotic%20soil001.JPG. [Accessed: 28- Apr- 2015].

[7] D. McIvor, *Birding Utah*. Helena, MT: Falcon Publ., 1998, p. 278.

[8] B. Prettyman, 'Utah Bucket List: Green River's clear fishing water, gorgeous view', *Salt Lake Tribune*, 2013.

[9] Nps.gov, 'Endangered Fish - Dinosaur National Monument (U.S. National Park Service)', 2015. [Online]. Available: http://www.nps.gov/dino/learn/nature/endangered-fish.htm. [Accessed: 25- Apr- 2015].

[10] Blue Castle Holdings, 'Introduction to Blue Castle Holdings and the Blue Castle Project ESP Application', 2011.

[11] Uraniumwatch.org, 'Uranium Watch: Blue Castle Project Water Rights', 2010. [Online]. Available: http://uraniumwatch.org/bluecastle.waterrights.htm. [Accessed: 29- Apr- 2015].

[12] Nuclear Regulatory Committee, 'TRIP REPORT – OCTOBER 2-6, 2011, PRE-APPLICATION READINESS ASSESSMENT (C-1) VISIT FOR AN EARLY SITE PERMIT AT THE BLUE CASTLE PROJECT SITE', 2011.

[13] "Summary of the Clean Air Act," United States Environmental Protection Agency, [Online]. Available: http://www2.epa.gov/laws-regulations/summary-clean-air-act. [Accessed 25 April 2015].

[14] "Clean Air," Nuclear Energy Institute, [Online]. Available: http://www.nei.org/Issues-Policy/Protecting-the-Environment/Clean-Air. [Accessed 20 April 2015].

[15] "Overview of Greenhouse Gases," United States Environmental Protection Agency, 4 April 2015. [Online]. Available: http://www.epa.gov/climatechange/ghgemissions/gases/co2.html. [Accessed 25 April 2015].

[16] "What is U.S. electricity generation by energy source?," U.S. Energy Information Administration, [Online]. Available: http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3. [Accessed 25 April 2015].

[17] "The Power Partners Annual Report," The Power Partners, January 2007. [Online]. Available: http://uspowerpartners.org/Reports&pubs/PowerPartners%28sm%29-AnnualReport-Jan2007.pdf. [Accessed 25 April 2015].

[18] "Irreversible climate change due to carbon dioxide emissions," *Proceedings of the National Academy of Sciences,* vol. 106, no. 6, pp. 1704-1709, 2009.

[19] Nei.org, 'Nuclear Energy Institute - Water Use And Nuclear Power Plants', 2015. [Online]. Available: http://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/Water-Use-and-Nuclear-Power-Plants. [Accessed: 28- Apr- 2015].

[20] J. Macknick, R. Newmark, G. Heath and K. Hallett, 'Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature', *Environ. Res. Lett.*, vol. 7, no. 4, p. 045802, 2012.

[21] Bluecastleproject.com, 'Blue Castle Project - Nuclear Power Utah - Faq', 2015. [Online]. Available: http://bluecastleproject.com/faq.php?faq_id=3. [Accessed: 28- Apr- 2015].

[22]S. Rogers, 'Nuclear power plant accidents: listed, visualised and ranked since 1952', *the Guardian*, 2011. [Online]. Available: http://www.theguardian.com/news/datablog/2011/mar/14/nuclear-power-plant-accidents-list-rank. [Accessed: 29- Apr- 2015].

[23] Dieselnet.com, 'Gaseous Emissions', 2015. [Online]. Available: https://www.dieselnet.com/tech/emi_gas.php. [Accessed: 28- Apr- 2015].

[24] N. Kajiyama, K. Hamamura and K. Murayama, *Hitachi's Involvement in Nuclear Power Plant Construction in Japan*, 1st ed. p. 48.

[25] Epa.gov, 'Nuclear Energy | Clean Energy | US EPA', 2015. [Online]. Available: http://www.epa.gov/cleanenergy/energy-and-you/affect/nuclear.html. [Accessed: 28- Apr- 2015].

[26] Nrc.gov, 'NRC: Backgrounder on Radioactive Waste', 2015. [Online]. Available: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html. [Accessed: 28- Apr- 2015].

[27]M. Masnik, *TRIP REPORT – OCTOBER 2-6, 2011, PRE-APPLICATION READINESS ASSESSMENT (C-1) VISIT FOR AN EARLY SITE PERMIT AT THE BLUE CASTLE PROJECT SITE*, 1st ed. 2011, p. Enclosure 3.

[28]*Blue Castle Plant Layout*. 2015.

[29]*Contaminant Structure*.

[30] *AP 1000 Overview*. 2011.

[31] "What if the Fukushima nuclear fallout crisis had happened here?," National Resources Defense Council, [Online]. Available: http://www.nrdc.org/nuclear/fallout/. [Accessed 25 April 2015].

[32] "Nuclear Power Plants," Ready, 11 February 2013. [Online]. Available: http://www.ready.gov/nuclear-power-plants. [Accessed 25 April 2015].

[33] "Nuclear Power Plant Accidents: Listed, Visualized, and Ranked since 1952," The Guardian, [Online]. Available: http://www.theguardian.com/news/datablog/2011/mar/14/nuclear-power-plant-accidents-list-rank. [Accessed 29 April 2015].

Chapter 8

Site Safety, Operations, and Security Protocols

Abstract

The safety of nuclear power plants, and therefore the safety of nuclear reactors, has evolved over the last several decades with the technological advances of the scientific community, as well as from lessons learned through the occurrence of severe accidents at existing plants. In this section the vulnerabilities of older generation reactors are analyzed, the steps towards minimizing future risk are identified, and the implications regarding safety protocols for areas that would fall within a plume zone are highlighted. The second looks at the daily elements of operation that are essential to the safety of the nuclear power facility. This includes the proper maintenance and accountability within the plant itself. The regulations during the initial construction are followed to a lesser extent throughout the life of the operation. The procedures outline what conditions must be maintained, how dangers are reported, and how the employees of the facility are protected their respective work environments. The chapter closes portion of the chapter discusses the elements of security required at a nuclear facility in terms of regulatory, cyber, and physical security. More specifically, the governing agencies and applicable regulations are introduced, as well as the measures taken at nuclear sites in order to both prevent, and combat a security threat.

8.1 Introduction

A nuclear power plant is an impressive structure in its magnitude and technology. It has the ability to generate copious amounts of electrical power to feed thriving communities for many years. The argument pertaining to the safety and reliability of nuclear energy is powerful on both ends of the spectrum, and one must be reminded that "with great power, comes great responsibility" [1]. Few man-made forces on this earth compare to the vast power and stored potential that exists within the confines of a nuclear reactor. A comprehensive analysis is given to discuss how such an operation is regulated, how it is kept safe from natural disasters, the role of the plant workers, and even how deliberate threats are to be managed.

Any concerns or presumed threats are taken seriously. There is no room for error or security breaches. The operators of a nuclear facility, the stakeholders involved, and the nearby public, are all greatly interested in continuous, safe functionality of the plant. The standards for safety and protection are built off the existing protocols of many government and private agencies. These agencies produce the criteria pertaining to how a facility is constructed and maintained, and how threats within and without the plant are mitigated. Any new facility is patterned from past experiences of what has worked. Depending on local concerns and topography, pre-existing standards are adjusted to provide a custom strategy for the needs of a proposed nuclear power plant.

The initial approach to this information began with an understanding of who the major controllers are in nuclear regulations. All standards are governed by various agencies, but the encompassing force over keeping most of this information is the Nuclear Regulatory Commission (NRC). This official server supplied a plethora of tangential information as it pertained to the specific operations and security measures of a nuclear power plant. This research prompted exposure to additional agencies and protocols. All of the information tied back to the central theme of the chapter as each new question arose, and the solution was discovered. Ultimately, many gaps of understanding were filled, and a thorough synopsis of site safety, operations, and security protocols was compiled.

8.2 Overseeing Agencies

Several agencies are involved with the assurance measures pertaining to a nuclear facility. The International Atomic Energy Agency (IAEA) is the international agency that advises nuclear energy as a member of the United Nations family. The IAEA promotes the safe, secure, and peaceful use of nuclear technology. Currently, there are 164 countries that are members of IAEA, including the United States [2]. This agency publishes a series of recommendations for safety and security measures for nuclear power plants. These security measures are only recommendations each individual country is responsible for mandating protocols.

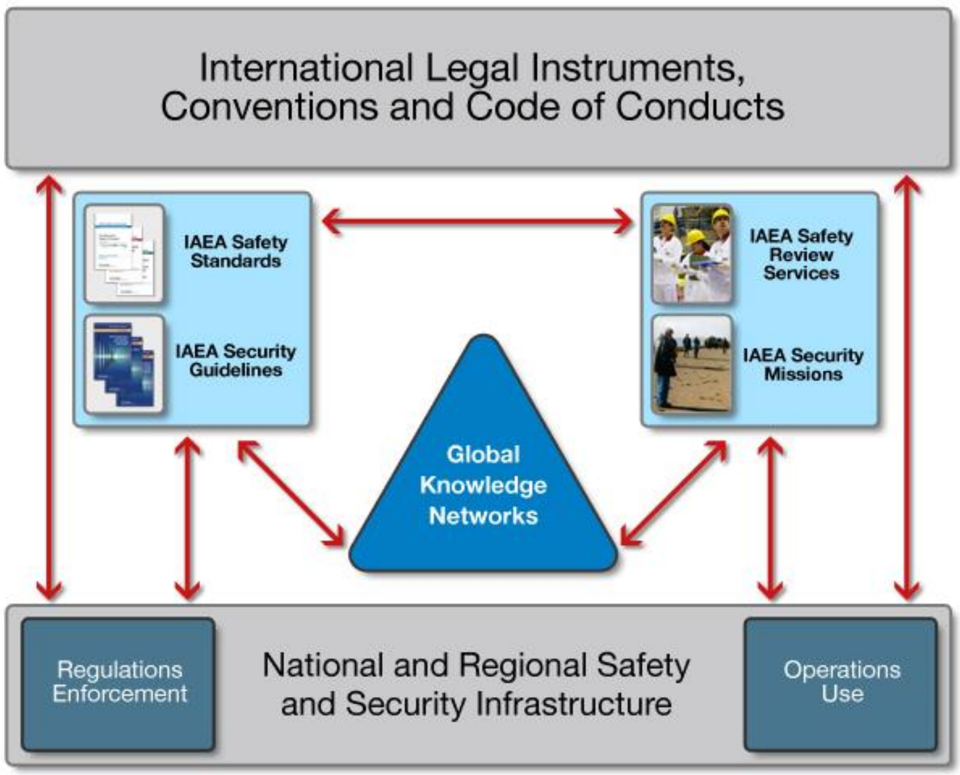


Figure 8.1: Flow Chart between International and National Agencies [3]**.**

In the United States, two governmental agencies exist that control safety and security protocols at nuclear power plants. According to the United States Government Accountability Office the responsibilities are split between The Department of Energy (DOE) and the NRC. The DOE is in charge of all government-owned and contracted facilities. Commercially owned sites, like the Blue Castle Project, adhere to the safety and security standards of the NRC [4].

8.3 Precautions and Response to Natural Disasters

The intention of the following section is not meant to cover all of the safety measures that go into the planning, construction and design of a nuclear power plant, but rather to discuss the safety related regulatory changes that have been implemented within the United States in recent years. Specifically, looking at the enhanced mitigation following the Fukushima Daiichi incident in Japan, and how those enhancements have manifested at the Blue Castle site.

8.3.1The Lessons of Fukushima

The damage sustained by Japan's Fukushima Daiichi nuclear power plant following the March 11, 2011 Earthquake and subsequent Tsunami, served as a grim reminder of the inherit dangers associated with the operation of a nuclear facility. The news of crisis in Japan hit at a time that the United States was experiencing an increased interest in nuclear power. The NRC was considering the approval of several licenses to construct new commercial nuclear reactors in the United States for the first time in nearly three decades. The news of Fukushima was met by congress with concern regarding the expansion of nuclear energy, as well as the implications for nuclear safety regulations in the United States. The NRC promptly responded to the apprehension by creating a task force to "conduct a systematic and methodical review of NRC processes and regulations to determine whether the agency should make additional improvements to its regulatory system and to make recommendations to the Commission for its policy direction, in light of the accident at the Fukushima Daiichi Nuclear Power Plant."

The task force conducted a review of the Fukushima Daiichi incident by analyzing the following three elements in terms of their relevance to reactors in the United States: protection against accidents resulting from natural phenomena, alleviating the effects of such accidents, and ensuring emergency preparedness. The recommendations from the review were later published in a July 12, 2011 report. A summary of the detailed recommendations is available in Appendix A [5]. The most relevant information to the Blue Castle Project comes from article 7 of the report, "Applicability And

Implementation Strategy For New Reactors," as such this will provide the premise for further discussion regarding nuclear plant safety requirements issued by the NRC based on the lessons learned from Fukushima [5].

8.3.2 Risk Assessment and Design Control of the AP1000 Reactor

The Fukushima accident was particularly alarming for the United States because, unlike Chernobyl, the Fukushima reactors are of similar design to many reactors currently operating in the United States. This raised policy questions concerning the continued operation of such reactors, and the design control of future reactors.

The Blue Castle Project will consist of 2 Westinghouse AP1000 nuclear reactors, which present the latest generation of nuclear reactors: Passive Generation III+. The Generation III+ design is the first reactor to receive certification from the NRC following the implementation of the NTTF's (Near Term Task Force) enhanced design considerations [5]. While detailed design specifications for the AP1000 reactor are provided in Chapter 3 of this text, the following parameters consist of those pertaining to the March 12, 2012 revision of nuclear plant safety regulations based on vulnerabilities cited in Fukushima. Specifically, the event of any natural catastrophe or other situation that could cause an extended loss of alternating current (AC) power, or a station blackout, is addressed.

Per the NRC AP1000 Design Certification Amendment (NRC-2010-0131),
the NTTF recommendations relevant to the AP1000 design certification are limited to: "seismic and flooding protection (Recommendation 2); mitigation of prolonged station blackout (Recommendation 4); and enhanced instrumentation and makeup capability for spent fuel pools (Recommendation 7) [5]." It was further noted that the task force determined the nature the passive design features, and inherent 72-hour coping capability of the AP1000 design hare satisfactory in addressing any further Task Force recommendations, and the NRC concluded that no changes to the AP1000 DCR are required at this time [6].

8.3.3 Seismic Characterization and Evaluation

Where nuclear power plants are concerned, design-based protection from natural phenomena is parameter intended to account for the event of failure contributed by site-specific risk to natural disaster. The associated guidelines, however, have been reevaluated to ensure consistency with the current state of knowledge and analytical methods, per Recommendation 2 of the NTTF, which states:

“The Task Force recommends that the NRC require licensees to reevaluate and upgrade as necessary the design-basis seismic and flooding protection of SSCs for each operating reactor [5].”

Although most plant designs provide adequate protection without risk-based modifications, if it is determined that implementing a design enhancement will offer a substantial safety improvement, and is reasonably justified in terms of cost, modifications to the plant design may be mandated. Furthermore, it is expected by the NRC that design-based safety criteria is evaluated prior to the approval of licensing and permits renewals, or in the event of a new site, such as the BCP, prior in obtaining an Early Site Permit (ESP) [7]. It was determined by the Task Force that the early site permits regulations already meet the requirements of recommendation 2 concerning the design-basis seismic and flooding analysis. While the geotechnical findings for the BCP (such as soil classification and properties) are detailed in Chapter 10 of this text, the information below discusses the process for evaluating and modeling the data [8].

8.3.4 Senior Seismic Hazard Analysis Committee (SSHAC)

The Senior Seismic Hazard Analysis Committee (SSHAC) is the entity responsible for the development of the SSHAC Guidelines described in the NUREG/CR-6372 document [9]. The procedures are intended to limit variability when conducting a probabilistic seismic hazard analysis (PSHA), by providing a methodology capable of generating reproducible, stable results. While, the primary goal of the SSHAC assessment method is to explicitly quantify uncertainty. The SSHAC guidelines are structures into four levels of hazard assessment at which studies can be conducted, where Level 1 study represents the simplest situation, and a Level 4 is the most complex and demanding [9]. As, such it is the expectation of the NRC that an SSHAC Level 3 or 4 study be performed for any site in the Western United States, which is a region of both complex, and active tectonic plates, and has the potential to cause significant public impact. Moreover, the SSHAC strategies have been updated in recent years not only by the Recommendations of the NTTF, but also by several other contributors [9]. The BCP analysis accounted for the most current procedure defined by the NRC.

Based on this guidance and the lack of an accepted SSC or GMC model for the BCH region, a SSHAC Level 3 study was deemed appropriate for the BCH ESP, while a Level 4 study was found to be unsuitable because from the regulatory perspective of there is essentially no difference between a Level 3 and Level 4 study. The Blue Castle SSHAC was then used to develop fully hazard-informed Seismic Source Characterization (SSC) and Ground Motion Characterization (GMC) models for use in the PSHA [9].

8.3.5 Probabilistic Seismic Hazard Analysis (PSHA)

According to the Practical Implementation Guidelines for SSHAC Level and 4 Hazard Studies published by the NRC, it was mandated that plants lying with in the South Western United States must provide a site-specific ground motion response spectrum (GMRS), safe shutdown earthquake (SSE) procedures, and to develop a Probabilistic Seismic Hazard Analysis PSHA.

The goal (PSHA) is to estimate the likelihood that various levels of earthquake-caused ground motion will be surpassed at a particular site within a given time frame. The NRC variability in quantifying technical data is minimized [9].

The two models used to develop the BCP PSHA were a Seismic Source Characterization (SSC), and a Ground Motion Characterization Model (GCM). The following illustrates how the two models relate to the formulation of the PSHA [9].

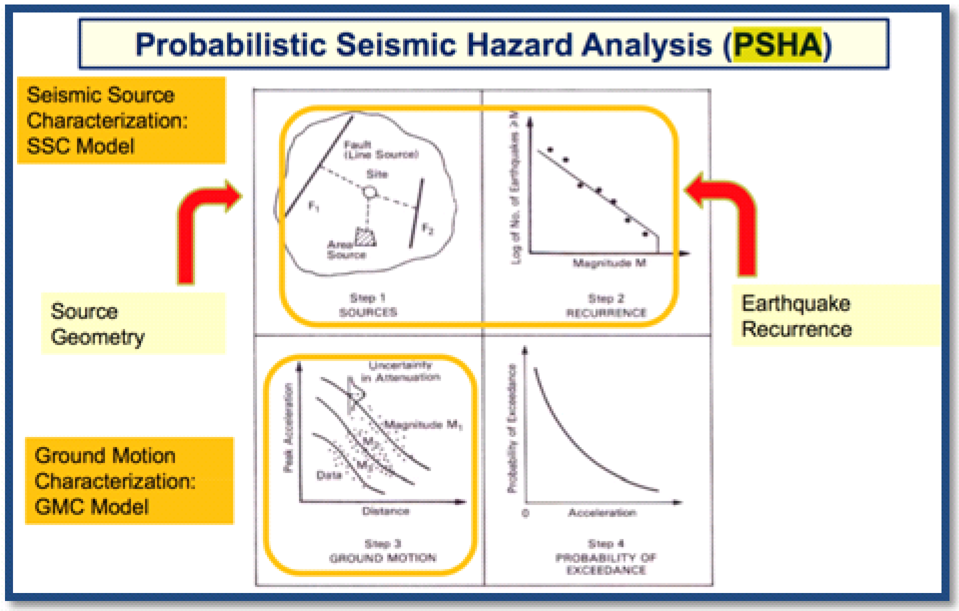


Figure 8.2: PHSA Flowchart [9].

The Seismic Source Characterization modeling involves a process to identify and characterize areal and fault sources. This was achieved by evaluating existing data compilations: USGS Quaternary fault and fold database, Utah, Colorado, and Arizona state surveys, and through a sensitivity analysis. It was concluded that Sangre de Cristo Fault is a source of not significant to hazard, while the faults within 40 kilometers are significant [9]. Additionally, the GMC model isolated several significant issues, which along the SSC data are discussed in Chapter 10. Ultimately, it was determined by the SSHAC that the BCH site adequately satisfies the regulatory requirements in terms of acceptable hazard values, and that the AP1000 plant design adequately protects against the risks posed by exposure to natural disaster.

8.3.6 Severe Accident Mitigation Design Alternative (SAMDAs)

The NRC has long expected all applicants for new nuclear reactors to examine severe accident-prevention and mitigation design features (SAMDA) as part of the ESP process. The NRC defines a SAMDA as a design feature, while a severe accident mitigation alternative (SAMA) is a feature or actions intended to prevent, or mitigate the consequences of severe accidents a nuclear facility. However, after the devastation at

Fukushima, Congress began to inquire as to whether United States nuclear power plants were adequately protected from severe accidents, particularly, in the event of an extended severe blackout.

Later, it was determined by the NTTF that although a situation similar to the Fukushima incident was unlikely to occur in the United States, the existing regulatory structure could benefit from improved mitigation. As such, the following recommendations to the SAMDA guidelines come as part of an initiative to enhance mitigation, per Recommendation 8 of Enhancing Reactor Safety in the 21st Century, in which the NRC Task Force advocates, "strengthening and integrating onsite emergency response capabilities such as emergency operating procedures (EOPs), severe accident management guidelines (SAMGs), and extensive damage mitigation guidelines (EDMGs) [9]."

Examination of alternatives to primarily design and procedures have been made for many licensed plants for which SAMAs have been chosen to better ensure safe, undue residual risk to the public is sustained throughout plant service life. That being said, the NTTF also stated that it would not be practical to integrate EOPs, SAMGs, and EDMGs prior to issuing construction and operating licensing (COL), but rather acknowledged it could require several years of effort by licensees, and the NRC staff.
Ultimately, the NTTF recommended a strategy that does not mandate integration until the plant in question is operating, at which time they licensee should also demonstrate that they have met the new requirements for prolonged SBO mitigation given in recommendation 4 [5]. As noted earlier, the AP1000 designs that will be used at the BCP already have many of the design features necessary to strengthen station blackout mitigation capability for design-basis and beyond-design-basis external events to address the task force recommendations regarding SAMDA.

8.4 Site Operations and Protocols

The success to providing a safe and reliable source of energy lies with the condition of the facility and how well it operates. All considerations and additional precautions exist to help mitigate public concern related to nuclear power. The practice of good caution is most rewarding in preparation of postulated malfunctions or accidents. If any failure of the equipment or violation to procedure is to occur, preemptive measures are already in place to minimize the treat which otherwise would have been significantly worse. In order to pacify any concerns outside of the power plant, great effort is taken within the plant to diligently monitor the facility, operation, equipment, and personnel. All of these components combine to protect the workers, and thereby protect the environment and any residents in the surrounding area.

8.4.1 Regulations for Licensing

Rigorous inspections are performed during the construction of a nuclear power facility, and similar checks are periodically conducted in order for the plant to remain licensed and operational. Initial criteria are subdivided during each phase of the construction process, but the task of overseeing every element of the facility can be overwhelming if not properly managed. Inspections are performed not only by the personnel inside the nuclear power plant, but by third-parties in the form of audits and compliance checks. The facility and all components related to the reactor are critical. The guidelines are explicitly outlined and regulated through the American Society of Mechanical Engineers (ASME) Section III. This section is the primary reference for all safety features pertaining to the “metallic materials” used [10]. This same ASME section also specifies that the structure and components receive regularly scheduled inspections. The measures for the inspections are to follow ASME Section XI [10]. These criteria are part of Division 1 manufacturing and maintenance standards due to the fact that this nuclear power plant uses light water cooling from the Green River [11]. Division 1 standards regulate the pipe and pump sizes, pressure gages, and other necessary mechanical components of the system. In addition, the code regulates inspection frequency, the qualifications of the inspector, and the method of record keeping. The major revising and renewal of a nuclear power plant's license to operate is addressed every 10 years, and the criteria is evaluated in accordance with the ASME standard, 10 CFR 50.55a(g)(6) [10] . If any repairs are needed, the Division 1 standards provide the correct discernment as to the extent of the repair, and who is authorized to perform them. This is includes, but is not limited to, the fabrication and installation of pipes or mechanisms [11].

8.4.2 Daily Operational Checks and Handling

In order to maintain a safe operation within the acceptable parameters, sensors, and gages are implemented throughout the facility. These Engineered Safety Features (ESF) are preventative measures in the event of emergency core cooling, breached contaminants, and even system failures [10]. Systems are in place to maintain any aging or failing components of a nuclear power plant, but ideally any possible threats will be caught and remedied by diligent daily monitoring. These safeguards ensure the well-being of the public.

In addition to the major audits which are scheduled periodically, the daily checks are handled by the plant workers and their direct supervisors. On a daily basis, temperature and pressure readings are taken from the reactor, the in-feed and out-feed lines, and through mechanical systems like pumps and valves. Leak rates, fracture inspection, seals, and isolation chambers, are also monitored throughout the day [10]. Any concerns are documented and reported to the Environmental Health and Safely (EHS) department [12]. This mandatory procedure went into full effect in 1975 for nuclear power plants. Documents are drafted and reviewed under the standards of Safety Analysis Reports (SARs) [10]. Since 1975, several revisions have been made to keep the reports current with new facilities and reactor types. More revisions are expected to take place due to future improvements and process modifications.

The reactor itself has a set of standards for inspection and reporting. Specific criteria is found in the ASME regulations for Division 1 plants under section 10 CFR 50.59 [10]. This process is not only monitored under the general SARs umbrella. Additionally, it uses a process called the Reactor Trip System (RTS) to ensure the reactor continues to operate within its designated parameters. This observes the heat generation from the reactor, through the transmission lines, and into the power conversion mechanisms. If the temperature gets to be too high, the system is equipped to shut down the reactor. This will stop the production of the nuclear reaction, and allow water to quench the chamber until the entire system cools back down to safe operating levels [10]. Once the reactor and transmission lines are considered to be back to sub-critical levels, the control rods can be retracted and the generation of energy resume.

8.4.3 Personnel Safety

Each job function is outlined and tested through a program of Standard Operating Procedures (SOP). The printed procedure is the outline for training and certification of all personnel. Tasks are followed and timed step-by-step to understand what needs to be accomplished, and eliminate room for error. This data is used to generate the cycle time of that particular operation, and ensure the efficiency of the process. In an effort to promote accountability and proper understanding of all important elements of training, each SOP is signed and dated by the trainer and the trainee [12]. These standards are also used to investigate and correct unsafe behavior. If a violation is discovered, each step of the process is reviewed to see if the error was a mistake, or negligence. The signed SOP can be used as legal documentation to hold employees accountable for their actions [12].

8.4.4 Personal Protective Equipment

Working in and around a nuclear power plant can be very hazardous to one’s health. Specific equipment including gloves, suits, footwear, respiratory equipment, and others, are all components of a worker’s Personal Protective Equipment (PPE). No substitutes or sub-grade products are allowed. Each type of PPE is manufactured to the specifications necessary for the nuclear reactor environment. This PPE has been regulated by the

American National Standards Institute (ANSI) since 1972 [13]. The office personnel and visitors have to follow protocol and be properly protected within their job function and risk of exposure. The slightest violation to improper use of PPE is dealt with swiftly, and prevents the worker from being allowed into their station. Corrective action, including termination, is possible depending on the violation [12]. Such judgment calls are made by supervisors and the EHS committee. The specific requirements of PPE are dependent upon the region of the nuclear facility and the job function. In and around the reactor is the most extreme even, though the AP1000 reactor is a contained system.

The risk for radiation exposure is low. The security and reliability of the reactor is attributed to good engineering. Even with all the fail-safes and preemptive measures, radiation levels are strictly monitored, and workers are equipped with Level APPE in accordance with the Occupational Safety and Health Administration (OSHA). This equipment consists of full respiratory protection and sealed hood. The bodysuit is totally encapsulated and protects against chemicals, vapors, and mild radiation. A chemical resistant inner suit must also be worn, along with both outer and inner protective gloves. Chemical resistant boots with a reinforced toe and shank are required. A hard hat must also be worn under the suit hood [13]. These suits get very warm inside and they limit mobility, so they cannot be worn for extended periods of time. They are not part of daily apparel, but need to be available to the workers in the event of an emergency or to service reactor.

Figure 8.3: Level A PPE Suit [13].

8.4.5 Employee Training and Readiness

Failure of any major component in the function of a nuclear power plant can be disastrous. Whether the problem is due to a system failure and the reactor overheats, or if damage is caused by some natural disaster, the employees and managers of a power plant need to possess the skills and knowledge to respond responsibly. Safety drills are conducted regularly in the emphasis of terrorist situations, tornados, earthquakes, floods, and meltdown proceedings. The frequency of the drills is dependent on the risks of the region where the nuclear facility is located [10]. All drills are conducted, but some are held more often if the area is more prone to one type of a disaster over another.

A basic level plant tour and training of PPE and evacuation proceedings must be accomplished within one week of hiring [12]. A rotation of system checks and training roles helps the workers be familiar with different job tasks in case an individual or an entire crew is unable to perform their duties during a time of need. Employees have the option to sign up and participate in safety teams – each having a different area of emphasis. An organized safety team is allowed to offer suggestions for changes which are evaluated by the limiting agencies. A team will work together in addition to their daily tasks in other areas of the nuclear power facility, for a period of six months before the teams are dissolved and new sign-ups are permitted [12]. This helps improve employee morale and allows cross-training.

8.5 Security

Security protocols for nuclear power plants are extremely important. The result of nuclear failures is catastrophic. Events like the Fukushima disaster have displayed the immediate and long-term effects of reactor failure. This type of devastation makes nuclear facilities a target for terrorism and other threats. Therefore, security measures required to safeguard nuclear plants are intricate and require cooperation between countries, governmental agencies, law enforcement, and many other entities to protect against both physical and cyber-attacks.

The Blue Castle Project will have to adhere to the security standards of the NRC, since it is commercially owned. The main goals of the NRC are to protect against theft and sabotage, to ensure the safety of the public. This is achieved by consultation with many governmental agencies, including the following:

- Federal Bureau of Investigation (FBI)
- Central Intelligence Agency (CIA)
- Department of Homeland Security (DHS)
- Federal Aviation Administration (FAA)
- Department of Defense (DOD)
- National Counter Terrorism Center
- Local and state police

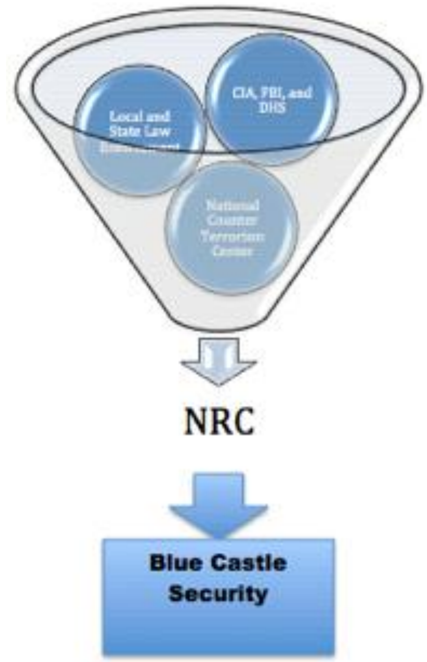


Figure 8.4: Generation of Regulations.

With the help of these agencies and others, the NRC is able to create strict security protocols which accomplish their objective [63]. The NRC security standards are the highest of any American industry according to the Nuclear Energy Institute (NEI) [15].

8.5.1 Security Personnel

Since the attacks of 9/11, security personnel requirements for nuclear facilities have been enhanced. Rigorous background checks for all employees are run through the Domestic Nuclear Detection Office and the National Counter Terrorism Center [16].The amount of security required has also been increased this assures that fatigue of guards is reduced to increase vigilance and effectiveness of the work force. A two-guard team, following what is called the “two-person” rule, monitors each post at a nuclear facility. This is designed to ensure that no unobserved access to nuclear material [16]. The security personnel are also subject to fitness evaluation to ensure the physical health of the guards [15]. Officers are trained in high caliber munitions and military training is preferred, but not required. The firepower allowed for plant guards vary between the DOE and NRC controlled facilities, but both permit guards to use deadly force when required [4]. All nuclear plants have security drills, which simulate terrorism attacks and robbery attempts.

Figure 8.5: Counter Terrorism Drills at the Nuclear Security Summit 2012 [17].

8.5.2 Zoning and Restrictions

The security zones at a nuclear plant are based on concentric circles. The concept is that the most important material is centered in the middle of the site, and barriers are created as the distance from the material increases. This system is used to protect the nation's critical infrastructure. At nuclear facilities, there are three zones. The zone closest to the reactor is called the Vital Area. Vital Areas contain the materials required for the safe shut down of the nuclear reactor [18]. Access to the vital area is granted on a need-to-be-there basis. To gain access to these areas, personnel must scan credentials and then identity is confirmed through a surveillance system by security guards. Once identification is confirmed, the door is unlocked remotely and access is granted. If the door remains open for too long, an alarm will sound. The zone that surrounds the vital area is called the protected area. Two twenty-foot barbed wire fences define the outside perimeter of protected area. All vehicles and personnel that pass this perimeter are searched and need the appropriate credentials to pass the access control point.

Figure 8.6: Three Security Zones of a U.S. Nuclear Plant [19].

The outer-most perimeter is called the owner-controlled area. This area is monitored by surveillance and has an access control point surrounded by a single twenty-foot barbed wire fence. Access to this zone varies depending on the state of national security. During normal operation, the owner-controlled zone is limited to people with business interests in the plant. If threats on national security heighten, however, access to the owner controlled zone is limited to critical employees. In all cases, if an individual does not have proper credentials, he or she must be escorted in the area by a person who possesses the proper credentials. These three zones encompass the on-site security at a nuclear plant and are broken down in Table 8.1 [18].

Table 8.1: Security Zone Breakdown.

Security Zone	Contained Infrastructure	Entrance Protocol
Vital Area	All elements of the nuclear facility that are used to safely shut down the reactor	Entrance based on a need-to-be-there basis. Credentials are scanned, and the door is opened remotely by security guards, after visual confirmation via surveillance equipment
Protected Area	The security infrastructure and the central alarm system	Entrance granted to those with the proper credentials after a search of the person and vehicle
Owner Controlled Area	The land between the property line and the protected area perimeter	Entrance varies depending on the national security threat level

8.5.3 Cyber Security

Modern technologies have formed a new access point for criminal activity. The Internet allows access to information from all areas of the world. This is why cyber security is becoming more prevalent in all business practices. Modern-day criminals are able to access operating systems and critical information that can destroy companies. According to the cyber security consultation firm, Black and Veatch, past cyber-attacks have been carried out for reasons including theft and sabotage [20]. These actions make cyber security critical for nuclear plants. The first line of defense for nuclear facilities is that all computers containing or controlling vital information are “air gapped” [21], which means they never have been and never will be connected to the Internet. This is the most important line of defense for cyber-attacks. Pertaining to the equipment that is connected to the Internet the NRC requires facilities to submit a cyber-plan, which the NRC reviews, and determines its adequacy. Once approved, the Cyber Security

Directorate, which the NRC created, monitors all cyber activity at the licensed site [22]. Upgrades to the Cyber security plan are reviewed every ten years as a part of the license review, and further changes can be made by the Cyber Security Directorate.

8.6 Summary

Thorough investigation of these safety and security protocols provide conclusive confidence that the BCP will establish safe and reliable nuclear power to southwestern cities. Thus far, the safety-related regulatory requirements surrounding the AP1000 plant design, and the associated site location, have either sufficiently met or exceeded the expectations of the NRC and the recommendations of the NTTF. Furthermore, it has been noted and agreed upon that as future safety enhancements - whether as part of the planned NTTF rollouts or otherwise - the BCP will be responsible to fulfill these requirements. Every precaution and regulatory standard will be upheld to the best interest of the workers inside the nuclear power facility, and to the communities it is near and services. The security of BCP will ensure the health and safety of the public. The strict protocols for personnel, zoning, and cyber security governed by the NRC will enable BCP to avoid any theft or sabotage of materials. The site and infrastructure will be safeguarded against all threats to ensure a secure nuclear facility.

8.7 References

[1] S. Lee, "Internet Movie Database," January 2015. [Online]. Available: http://www.imdb.com/title/tt0145487/quotes. [Accessed 23 April 2015].

[2] International Atomic Energy Agency, "Nuclear Security Guidelines," 9 December 2014. [Online]. Available: http://www-ns.iaea.org/security/nuclear_security_series.asp. [Accessed 15 April 2015].

[3] Global Nuclear Saftey and Security Network, "The Global Nuclear Safety And Security Framework," January 2015. [Online]. [Accessed 16 April 2015].

[4] U.S. Government Accountability Office, 11 September 2007. [Online]. Available: http://www.gao.gov/products/GAO-07-1197R. [Accessed 15 April 2015].

[5] U. S. N. R. Commission, "Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," 12 July 2001. [Online]. Available: http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf. [Accessed 10 April 2015].

[6] T. L. Schulz, "Westinghouse AP1000 advanced passive plant," Science Direct, pp. 1-11, 2006.

[7] A. Kammer, "The Nuclear Regulatory Commission," The Nuclear Regulatory Commission, April 2012. [Online]. Available: http://pbadupws.nrc.gov/docs/ML1211/ML12118A445.pdf. [Accessed 12 April 2015].

[8] Engineering The Future, "Nuclear Lessons Learned," The Royal Academy of Engineering on behalf of Enigineering the Future, London, 2010.

[9] U. N. Nuclear, "Practical Implementation Guidelines For SSHAC Level 3 and 4 Hazard Studies".

[10] U. N. R. Commisson, "Reactor License Renewal Guidance Documents," December 1991. [Online]. Available: http://www.nrc.gov/reactors/operating/licensing/renewal /guidance.html#standard. [Accessed 6 April 2015].

[11] A. Chugh, "ASME Piping Guide," 2011. [Online]. Available: http://www.pipingguide.net/2013/05/asme-section-xi-rules-for-in-service.html. [Accessed 16 April 2015].

[12] C. Boyce, "Environmental Health and Safely Annual SOP Review," Cardinal Health, Englewood , 2014.

[13] U.S. Department of Health and Human Services, "Radiation Emergancy Medical Management," National Library of Medicine, 21 November 2014. [Online]. Available: http://www.remm.nlm.gov/osha_epa_ppe.htm. [Accessed 25 April 2015].

[14] United States Nuclear Regulatory Commission, 9 January 2015. [Online]. Available: http://www.nrc.gov/security/faq-security-assess-nuc-pwr-plants.html#15. [Accessed 15 April 2015].

[15] Nuclear Energy Institute, "Nuclear Power Plant Security," September 2014. [Online]. Available: http://www.nei.org/master-document-folder/backgrounders/fact-sheets/nuclear-power-plant-security. [Accessed 15 April 2015].

[16] G. Aloise, "Director of Natural Resources and Environment," 2007.

[17] CCTV, 16 March 2012. [Online]. Available: http://english.cntv.cn/program/newsupdate /20120316/117776.shtml. [Accessed 15 April 2015].

[18] P. G. Castleberry W., May 2013. [Online]. Available: http://www.pdhcenter.com/courses/e182/e182content.pdf. [Accessed 16 April 2015].

[19]Florida Power and Lighting, January 2015. [Online]. Available: https://www.fpl.com/clean-energy/nuclear/plant-security.html. [Accessed 15 April 2015].

[20] Black and Veatch, "Cyber Security for the Nuclear Power Industry," January 2012. [Online]. Available: http://bv.com/docs/energy-brochures/nuclear-cyber-security. [Accessed 27 April 2015].

[21] Nuclear Energy Institute, "Cyber Security for Nuclear Power Plants," NEI, April 2015. [Online]. Available: http://www.nei.org/master-document-folders/backgrounders/policy-briefs/cyber-security-regulated-by-nrc;-no-addit. [Accessed 28 April 2015].

[22] US NRC, "Cyber Security and Digital Instrumentation and Controls," March 2015. [Online]. Available: http://www.nrc.gov/about-nrc/regulatory/research/digital/key-issues/cyber-security.html. [Accessed 27 April 2015].

Chapter 9

Nuclear Waste: Treatment and Disposal Techniques

Abstract
The concern of this chapter is the treatment and disposal of spent nuclear fuel. Utah has been subjected to nuclear radiation in the past, which has warranted further research and analysis to ensure the proper disposal and storage techniques may be implemented in the Blue Castle Project. From our research we were able to conclude that the Green River site is an appropriate area for onsite storage of the spent nuclear fuel. Currently there are no known methods for permanent disposal of spent nuclear fuel.

9.1 Introduction

Southern Utah and Nevada are no strangers to the negative impacts nuclear radiation can have. A Google search for "Utah Nuclear Testing" will provide you with some spectacular atomic bomb images and several articles explaining why there would be opposition to this power plant from the people native to this area. A lot of nuclear testing for the atomic bomb was conducted in the vastly uninhabited, governmentally owned deserts of Nevada, which are located adjacent to Southern Utah. There is a prevailing easterly wind system that carries debris downwind from Nevada to Utah. "The downwinders" are a community that is still affected to this day by the nuclear testing done in the 1950's. Several generations of these people geographically located downwind of the testing sites have been found to have abnormally high incidences of infertility, miscarriages, birth defects, and cancer. This abnormality is statically correlated to the amount of exposure to radioactive materials. The Radiation Exposure Compensation Act was passed largely due to the downwinders and the multitude of lawsuits that had been filed since the 1950's regarding their health. This bill passed in 1990 and "created a $100 million dollar trust fund to compensate citizens who lived downwind from above ground atomic tests and later were stricken with radiation-related illnesses"[6]. Part of the legislation states:

> The United States should recognize and assume responsibility for the harm done to these individuals. And Congress recognizes that the lives and health of uranium miners and of innocent individuals who lived downwind from the Nevada tests were involuntarily subjected to increased risk of injury and disease to serve the national security interests of the United States. The Congress apologizes on behalf of the Nation to the individuals...and their families for the hardship they have endured [6].

History often repeats itself, however have we as a society learned from our mistakes? It would prove that as a society we have not learned, if in another 50-60 years the government put out another bill, apologizing and creating a trust fund for those people who were involuntarily subjected to increased risk of injury and disease to serve the national power supply interests of the United States. Further analysis and research has been conducted to answer the power supply questions of the future.

9.2 Nuclear Power

Nuclear power comes from fission, which is a nuclear reaction where a large element breaks down into a smaller element or series of smaller elements. This is known as radioactive decay. Radioactive decay is dangerous because the material is constantly breaking down and emitting particles into the surrounding media. When these emitted particles collide with another object their energy is given off. This energy release and transfer leads to a chain reaction in reactivity, which is what sustains nuclear power. However, if the radiation penetrates a living organism the energy dissipated may cause mutations on an atomic level, which may lead to cancer.

9.3 Amount and Location of Fuel Source

Radioactive decay happens in many naturally occurring elements such as Carbon, Potassium, Uranium and Plutonium. When these materials are concentrated in a small area they release a massive amount of energy in the form of heat. Uranium is the radioactive element used as a fuel source in all currently operating power plants. It is mined like any other metal ore and is as abundant as zinc or tin [4]. There is 5,902,500 tons of Uranium that can still be recovered in an economically feasible process with our current mining practices and the current price of Uranium. Uranium mines can be found in 20 different countries, however "52% of world production comes from just ten mines in six countries" [4]. These six countries provide 85% of the world's supply of mined Uranium [4]. It is known to commonly occur in two isotopes Uranium-235 (U-235) and Uranium-238 (U-238). Both isotopes are found together in small concentrations in rocks and have to be refined to become a usable source of fuel.

9.4 Enriching Uranium

U-235 makes up less than one percent of all naturally occurring uranium; U-238 makes up the other 99 percent. U-238 is less reactive than U-235 and not a useable fuel source, so the Uranium has to be divided into specified proportions. This process is known as enriching. U-238 has three more neutrons in its nucleus than U-235, causing it to weigh slightly more. Scientists take Uranium in its naturally solid state and chemically react it to get it into the gas phase. Once in the gas phase it is placed into large cylindrical centrifuges that spin on their axis causing the heavier particles to gravitate toward the middle. After each spinning cycle the outermost gas, gas containing a higher U-235 ratio, is removed and placed into a new centrifuge and the process is repeated until the desired U-235/U-238 ratio is met. This process requires precise science and engineering that is not available in most countries. If converted to today's dollars, the cost to enrich the 137 pounds of U-235 used to make the atomic bomb America dropped on Hiroshima would be about 6 billion dollars [1].

Once the Uranium is enriched to contain around 2-3% U-235 and 97-98% U-238, the higher concentration of U-235 is used to sustain a fission chain reaction. As previously mentioned this reaction gives off a massive amount of heat, which is used to boil water that drives a turbine to create electricity. Of the fuel used in a nuclear reactor, about 96% of Uranium is leftover. This depleted Uranium is no longer efficient enough to produce the heat required to drive the reaction and is currently considered to be "spent" nuclear fuel [5]. This fuel is removed from the reactor every 12 to 18 months and replaced with newly enriched fuel. [2] Figure 9.1 shows a timeline of the natural degradation of U-238. This isotope of Uranium has a half-life of 4.5 billion years. Half-life is the time taken for the radioactivity of a specified isotope to fall to half its original value. For instance, if there were 100 grams of U-235 today, it would take 4.5 billion years to have 50 grams of U-238 and 50 grams of the non-radioactive lead.

Also shown in Figure 9-1[1] are other radioactive elements that are formed in the process. Some of the radioactive elements in spent fuel have short half-lives. For example, iodine-131 has an 8-day half-life, meaning it's radioactivity decreases rapidly. However, many of the radioactive elements in spent fuel have long half-lives. For example, plutonium-239 has a half-life of 24,000 years, and plutonium-240 has a half-life of 6,800 years. Because it contains these long half-lived radioactive elements, spent fuel must be isolated and controlled for thousands of years [2].

[1] There are many other radioactive decay series present in a nuclear reaction, Figure 9-1 is a simplified version to demonstrate the length of time and general process involved in radioactive decay.

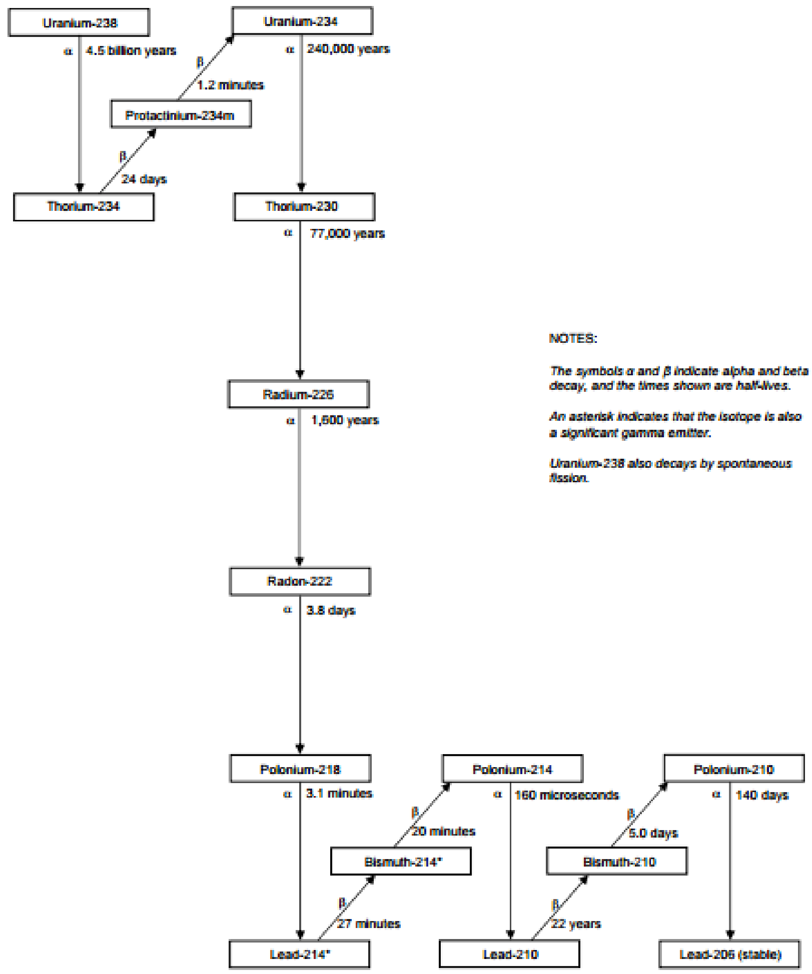


Figure 9.1: Decay Series of Uranium 238 [3].

9.5 Waste Production

There are three levels of radioactive waste, low level, intermediate level, and high-level waste. Spent nuclear fuel and the nuclear power plant processes contribute to all three levels of radioactive wastes.

9.5.1 Low-Level Waste (LLW)

This waste is generated from hospitals, industrial/chemical facilities, and the nuclear fuel cycle. It is made up of paper, tools, clothing, filters and other materials, which contain small amounts of radioactivity. This waste does not require shielding during handling and transportation and is suitable for the current landfill systems. Its volume is reduced by compaction or incineration before disposal. Low-level waste makes up about 90% of the volume but only 1% of the radioactivity of all radioactive waste, including nuclear waste [5].

9.5.2 Intermediate-Level Waste

This waste contains higher amounts of radioactivity and requires some shielding during transportation and handling. It is typically composed of resins, chemical sludges and metal fuel cladding, as well as contaminated materials from reactor updating and restoring existing reactors. Smaller intermediate level waste items and any non-solid wastes may be mixed into concrete to form a solid that is safe to dispose of using current landfill techniques. Intermediate level wastes make up around 7% of the volume and 4% of the radioactivity of all radioactive waste [5].

9.5.3 High-Level Waste

Spent nuclear fuel makes up high-level waste. “Spent nuclear fuel is highly radioactive and potentially very harmful. Standing near unshielded spent fuel could be fatal due to the high radiation levels” [5]. Ten years after removal of spent fuel from a reactor, the radiation dose one meter away from a typical spent fuel assembly exceeds 20,000 rems per hour. A dose of 5,000 rems will cause immediate incapacitation and death within one week [2].

9.6 Storage Techniques

Spent fuel must be isolated and controlled for thousands of years due to its long half-lived radioactive elements. Nuclear Regulatory Commission (NRC) regulations require stringent design, testing and monitoring in the handling and storage of spent fuel to ensure that the risk of an accidental splitting or self-sustained fission of the atoms of uranium and plutonium does not occur. For example: Special control materials (usually boron) are placed in spent fuel containers to prevent a criticality from occurring. “Nuclear engineers and physicists carefully analyze and monitor the conditions of handling and storage of spent fuel to guard further against an accident. A barrier or radiation protection shield must always be placed between spent nuclear fuel and human beings" [2]. Two types of waste storage, wet storage and dry storage, will be examined further.

9.6.1 Wet Storage

About 90% of the world's spent nuclear fuel is in storage pools, with the remaining contained in dry storage facilities [5]. Most of this fuel is of the high level waste type, and has been there for many decades. After the enriched uranium has run its useful life, it is moved to a storage facility to allow the radionuclides to decay over time.

"Currently most spent nuclear fuel is safely stored in specially designed pools at individual reactor sites around the country. The water-pool option involves storing spent fuel in rods under at least 20 feet of water, which provides adequate shielding from the radiation for anyone near the pool"[2]. Such great depths are necessary to keep the large amounts of radiation from exiting the pool into the air. The fuel rods are moved into the water pools from the reactor along the bottom of water canals, so that the spent fuel is always shielded to protect workers [6]. A typical spent fuel rod is about 12 feet long and 3/4 inch in diameter [6].

Although the fuel is no longer being used to create energy, it still contains a high level of radionuclides and therefore generates a lot of heat. For this reason, these pools are robust constructions made of thick reinforced concrete with steel liners. To ensure the temperature of the storage pool is kept below 100 degrees Fahrenheit, circulation systems must be put in place [5]. Water in these pools is filtered and purified, then circulated through a heat exchanger for cooling and returned to the top of the pool [6]. Figure 9.2 is an example of a typical storage pool.

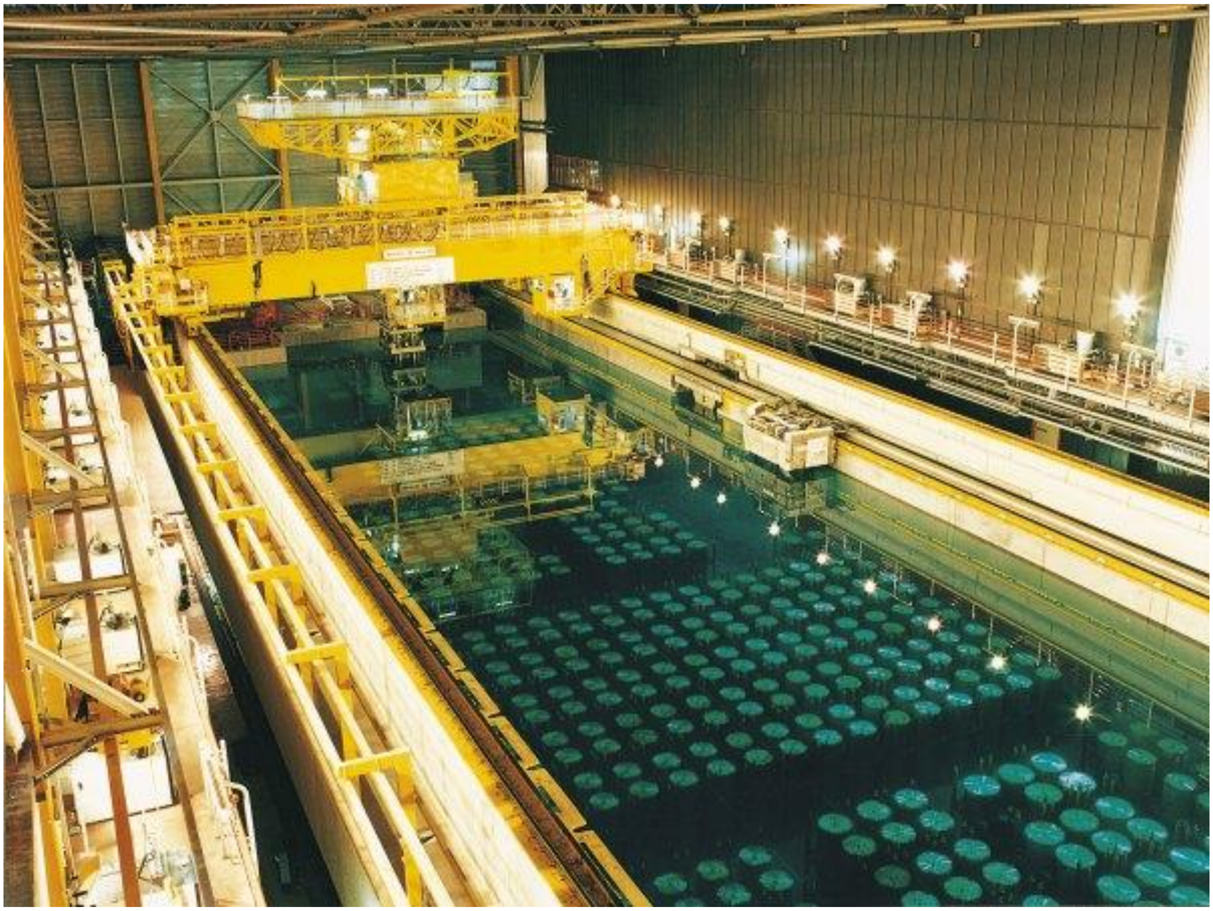


Figure 9.2: Example of a typical storage pool used for cooling the fuel rods [5].

Storage pools such as the one above are designed to operate for the lifecycle of the power plant, and are often constructed to hold all the spent fuel the reactor will generate. However in some cases, the capacity of the storage pool must been increased through “(1) enlarging the capacity of spent-fuel racks, (2) adding racks to existing pool arrays ("dense-racking"), (3) reconfiguring spent fuel with neutron-absorbing racks, and (4) employing double-tiered storage (installing a second tier of racks above those on the pool floor)”[8]. The fuel rods shown above are kept completely submerged for between 5-10 years before can be moved to a dry storage facility.

9.6.2 Dry Storage

Once storage pool capacity is reached, licensees move toward use of aboveground dry storage casks. The NRC licensed the first dry storage installation in 1986 [4]. “In this method, spent fuel is surrounded by inert gas inside a container called a cask. The casks can be made of metal or concrete, and some can be used for both storage and transportation. They are either placed horizontally or stand vertically on a concrete pad"[2]. Each steel casks or multi-purpose canisters (MPCs) can hold up to 80 fuel assemblies and may be used for eventual disposal of the used fuel [2]. The casks are commonly level with the ground surface, about 6m high, and cooled by air convection. In some cases they may be below grade, with just the tops showing [2].

Although dry storage is not suitable for fuel until the fuel has been out of the reactor for a few years and the amount of heat generated by radioactive decay has been reduced, dry storage is simpler than pool storage. It uses fewer support systems and offers fewer opportunities for things to go wrong through human or mechanical error [6]. Wet storage requires a greater and more consistent operational vigilance on the part of utilities or other licensees and the satisfactory performance of many mechanical systems using pumps, piping and instrumentation. Also due to its relatively low land demand (less than half an acre in most cases) dry storage is becoming a more popular method of high-level waste storage [2]. Currently, dry storage is in use at about 5 percent of all nuclear sites [5]. Figure 9.3 shows an example of what a dry storage facility looks like.

Figure 9.3: Example of Dry storage casks used to store fuel rods [2].

9.7 Storage of LLW's

Although Low Level waste comprises almost 90% of the volume of radioactive wastes, it only accounts for 1% of the radioactivity of all nuclear waste [6]. The storage of this waste requires an NRC or Agreement State license. "NRC or Agreement State regulations require the waste to be stored in a manner that keeps radiation doses to workers and members of the public below NRC-specified levels"[2]. These regulations are the max amount of radiation that can be leaked; in many cases the actual doses are a small fraction of the NRC limits [2]. Low-level radioactive waste is packaged in containers appropriate to its level of hazard. Workers are trained to maintain a safe distance from the more highly radioactive materials, to limit the amount of time they spend near the materials, and to monitor the waste to detect any releases. To reduce its volume, it is often compacted or incinerated before disposal.

9.8 Storage Locations

Currently, the United States has no permanent repository for high-level nuclear waste. All nuclear power plants in the United States do on-site storage, which is approved and licensed by the NRC or may store it at another approved site [2]. The only site being considered by the Department of Energy (DOE) is Yucca Mountain, which is located in Nevada, about an hour northwest of Las Vegas. For more than 20 years there have been scientific studies done on Yucca Mountain's geology to determine if it is feasible, safe, and adequate to store the highly radioactive waste deep underground. However, research has shown potential problems at the site. It is located in the desert and it is in an extremely active earthquake zone. An aquifer is located beneath the mountain, and the people who live near the Yucca Mountain are dependent on the aquifer for drinking and irrigation. There are major health concerns that need to be considered. Even if the Yucca Mountain site was approved it will not accommodate all the waste projected. According to Nuclear Information Resource Services, the United States will exceed the 70,000 tons of capacity that the Yucca Mountain offers [9]. There has to be more scientific research done to properly store the nuclear waste produced by the Blue Castle Waste Project.

9.9 Regeneration of Nuclear Waste

An alternative to nuclear waste disposal is recycling used nuclear spent fuel. In the United States the fuel is used once in the reactor and then removed for ultimate disposal. This method is called an "open" fuel cycle. The method of recycling and reusing the uranium fuel is called a "closed" fuel cycle. A closed fuel cycle is an approach that would capture the remaining energy in the spent fuel waste. The biggest operator of reprocessing fuel in the world is AREVA, La Hague, France [7].

9.9.1 AREVA, La Hague, France

La Hague facility started in 1966, and is located in the Manche region of France. La Hague is designed to receive and process spent fuel originating from France's nuclear power plants, and overseas power plants. All foreign fuel received is returned to its country of origin after processing. The plant has a capacity for annual processing of 1,700 tons of spent nuclear fuel. This amounts to 80-100 nuclear reactors. When spent fuel waste is removed from the nuclear power plant it contains 96% recyclable material

(95%uranium and 1% plutonium), which can be reused as fuel. If this method is implemented, then only 4% of all nuclear fuel is considered actual waste. In order to achieve a high quality process there are four major steps that need to be implemented.

9.9.1a Reception and Storage

The safety of the shipping mainly depends on the container that the material will be transported. The assemblies are packed in casks and shipped to AREVA's plant in La Hague. After arriving the material is re-stored on site using the dry or wet methods discussed earlier. The fuel elements are then placed in frames and sent to interconnected interim storage pools where they are submerged nine meters under water for up to five years to help reduce heat from radioactive elements.

9.9.1b Separation and Purification of Uranium and Plutonium

Once the cooling period has ended, the fuel element is transferred to the shearing facility where the rods containing the spent fuel are cut into three and half centimeter segments. These segments fall into a tank known as a dissolver, which contains nitric acid. The nuclear material is dissolved in the nitric acid solution and transferred to the chemical separation facility. The metallic segments of the fuel rods are then removed using a bucket wheel and sent to a conditioning unit. At the chemical facility the Uranium and Plutonium are separated and purified.

9.9.1c Recovering Energy Materials

After the Uranium is purified, the solutions are concentrated by evaporation in the form of uranyl nitrate. Then it is properly stored, checked, packed and transported to plants for its recycle or storage in their solid forms. Uranium is later reused for manufacturing nuclear fuel. The Plutonium is converted to powder called plutonium oxide, and packed in stainless steel containers. Each container is sent back to its original plant to manufacture new Mixed Oxide Fuel.

9.9.1d Waste Conditioning

The recyclable material is treated and the final residue is processed. All liquid effluents generated throughout the regeneration process are treated and checked before being released into the atmosphere. The metallic structures that were holding the spent fuel are compacted and placed in containers. Finally the fission products, or what is consider “actual waste”, is stabilized by the method of vitrification. During vitrification the liquid waste will be calcined and then incorporated in a glass matrix, which will contain all the radiation. This mixture will then be poured into stainless steel containers and put into storage.

9.10 Conclusion

The implementation of the regeneration process in the United States would be extremely beneficial and environmentally friendly. However, the use of regeneration plant will require a combination of advanced reactors, new federal policies and financial investment. It is an alternative that needs to be considered. In the case of The Blue Castle Project, the ability for on-site storage is very feasible due to the relatively unused land surrounding the proposed site. Both dry storage and wet storage may be implemented effectively at this site. After conducting this research, it has been determined that the Green River site for the Blue Castle project is appropriate for the current treatment and disposal techniques of nuclear waste.

9.11 References

[1] Live Science.com, “How Is Uranium Enriched?”*LiveScience*. TechMedia Network, 18 May 2010. [Online]. Available: http://www.livescience.com/. [Accessed: 25 Apr- 2015].

[2] Nrc.gov, “Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437 Vol. 1).” *United States Nuclear Regulatory Commission*. [Online]. Available: http://www.nrc.gov/reading-rm/doc-collections/. [Accessed: 25 Apr- 2015].

[3] Gonuke.org, “Natural Decay Series: Uranium, Radium, and Thorium.” [*Argonne National Laboratory, EVS*. Web. Online]. Available: http://gonuke.org/ComprehensiveTeaching Toolkits/Radiation Protection/ChSCCRP/Columbia Basin RPT-111/Supplementary materials/natural-decay-series.pdf. [Accessed: 25- Apr- 2015].

[4] World-nuclear.org, “Supply of Uranium.” *World Nuclear Association*. [Online]. Available: http://www.world-nuclear.org. [Accessed: 25- Apr- 2015].

[5]World-nuclear.org, “Radioactive Waste Management.” *World Nuclear Association*. Web. 25 Apr. 2015. [Online]. Available: http://www.world-nuclear.org. [Accessed: 25- Apr- 2015].

[6] Historytogo.gov, “Utah History to Go.” *Utah History to Go*. Web. 25 Apr. 2015. [Online]. Available: http://historytogo.utah.gov/. [Accessed: 25- Apr- 2015].

[7] Areva.com, “AREVA La Hague: recycling used fuel - AREVA.” [Online]. Available: http://www.areva.com/EN/operations-1092/areva-la-hague-recycling-used-fuel.html. [Accessed: 24- Apr- 2015].

[8] Nei.org, “Nuclear Energy Institute - Used Fuel Storage Pools at Nuclear Energy Facilities Are Safe,” 2013. [Online]. Available: http://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/Used-Fuel-Storage-Pools-at-Nuclear-Energy-Faciliti. [Accessed: 25- Apr- 2015].

[9] State.nv.us, “Earthquakes In The Vicinity Of Yucca Mountain.” [Online]. Available: http://www.state.nv.us/nucwaste/yucca/seismo01.htm. [Accessed: 24- Apr- 2015].

[10]*Yucca Mountain, Nevada and Nuclear Waste*, 1st ed. Washington, 2015, pp. 1-2.

[11] Nei.org, “Nuclear Energy Institute - Repository Development,” 2015. [Online]. Available: http://www.nei.org/issues-policy/nuclear-waste-management/disposal. [Accessed: 25- Apr- 2015].

Chapter 10

Geotechnical Report: Site Feasibility

Abstract
A geotechnical investigation was conducted in order to determine the feasibility of the Blue Castle Holdings nuclear power plant. Soils with problematic geotechnical properties cause widespread and costly problems that represent a hazard to any construction project, especially for a project with as high a risk factor as a nuclear power plant. This investigation examines the classification of pre-existing soils at the proposed site, the groundwater conditions, the viability of different methods to improve the soil for construction, the potential for swell or collapse, any potential problems related to frost heave, and any seismic issues.

The soil types present at the site are mostly fine-grained soils, and the majority of those fine-grained soils are classified as clays. Fine-grained soils, especially those with high percentages of clay, are more susceptible than coarse-grained soils to many of these problems because their properties vary as the water content in the soil changes. Chemical remediation by the addition of cement is a technology for stabilization of these soils. Due to low ground slopes at the proposed site, landslides should not be a factor. The site is situated roughly 300 feet above the water level in the Green River, which negates any concerns over flooding from the river. Due to a lack of proximity to any faults within 200 miles, seismic problems are unlikely. Therefore, the site is feasible for a large scale construction project after chemical remediation of the clay.

10.1 Introduction

The most widespread and costly related problems are found in soil and rock for geological settings. Geologic materials have characteristics that make them vulnerable to volumetric changes, collapses, or other geologic-engineering related problems [1]. These characteristics make development difficult since geologic conditions must be investigated prior to construction and understanding the geological related issues is time consuming. However, the developed knowledge of soil and rock related problems will prevent a structural failure on the foundational level, which, in turn will avoid costly corrective measures and environmental damages, post-development.

Utah has a unique geology and climate that must be considered for Emery County. There are around 9 types of problem soils done by the Utah Geological Survey that can be prevalent in Utah [1]. The geological related issues are:

a) Expansive soil and rock with high shrink and swell potential
b) Collapsible or hydrocompactible soil
c) Gypsum and gypsiferous soil susceptibility to dissolution
d) Limestone which is susceptible to failure under certain hydrological conditions.
e) Soil subject to piping which is a localized subsurface erosion
f) Active dunes
g) Highly compressible peat, subject to volume change
h) Underground mines
i) Soil containing sodium and sulfate

However, the investigation of the nuclear power plant site will focus on various aspects related to expansive soil and rock, collapsible or hydrocompactible soil, and the prevalence of gypsum.

The geology and climate influences the distribution of soil and rock. The type of problem that may occur in the geologic material is derived from studying the parent material. Expansive soil is a problem for Utah, as it is prevalent for approximately 15 percent of the state [1]. For example, shale and karst formation in limestone and gypsiferous are associated to expansive soil conditions. Expansive soils are unstable for large foundational structures. The parent material of the expansive soil is important to study in order to provide sufficient information for developing the structure.

The investigation is based on the soil data reports in the nearby area of Green River, UT. The available data gathered are primarily from sources of reports that are from state, local, and federal government investigations. The soil reports utilized for the nuclear power plant geotechnical investigation retrieved from the United States Department of Agriculture. The data represents reports of soil conditions, classification, and type of soil distribution by depth.

10.1.1 Purpose and Scope of Services

The goal of the geological investigation is to discover the potential that may arise within the soil foundation for nuclear power plant development. The investigation aims to mitigate any problem that can cause a setback in the pre-, post-, and current development of the nuclear power plant, as it relates to geological material the structured is founded on before the actual development. If all geological issues are accounted for, then the prevention of costly corrective measures for post development and environmental disasters will be avoided.

The extent of the geotechnical investigation focuses on geological overview of the Green River area, the location and surface soil conditions, the subsurface soil conditions, the groundwater conditions, the classification of soil, the viability of compaction and the stabilization of soil at site area, the shrinkage/expanding potential of soil, the frost heaving susceptibility, and the seismic potential. The extents of the investigation are limited on the resources available to undergraduate students at the University of Utah. One of them is access to Blue Castle's project plans for the development of the nuclear power plant. Another is the lack of time and equipment to do a primary investigation of the soil and rock at the site of interest. The information on the soil and rock are from past reports and investigation of nearby areas by government, state, and local agencies.

10.1.2 Investigation Summary

10.1.2a Classification of Soil

Soil size characteristics are classified into two categories which are coarse grained or granular and fine grained soils. The two categories can be broken into two additional subcategories that are dependent on particle size. The division of size of particles depend on which classification system chosen to characterize the soil. There are two systems are the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials. The detail on either classification system are located in section 10.2.

10.1.2b Subsurface Conditions

The subsurface conditions of soil are a Chipeta-Badland and Ravola-Garley soil complexes. The site location has more than the half the area comprising of the two soil complexes. The Chipeta-Badland and Ravola-Garley soil complexes are located at the surface and extend a certain depth down. The two soil complexes have a different distribution of coarse and fine grained particles. The detail and figures in regards of these two soil complexes are found in Figure 1 and Figure 2.

10.1.2c Compaction/Stabilization

The soil stabilization and compaction behavior is based on the type of soil that is available in the area. The soil on the top layer at the site is Chipeta soil. The layer below the Chipeta is Mancos shale. The Chipeta soil and Mancos shale have properties that unfavorable geological problems with collapsibility and expansiveness. The stabilization method would be required for the two types of soil. Compaction and chemical stabilization are methods investigated as techniques to provide solid foundation. Further details on compaction and stabilization are in section 10.2.

10.1.2d Groundwater Conditions

The groundwater conditions are considered for the potential impact of contaminant travel to the water table. The groundwater systems are not static and continually to adjust from variables such as climate, municipal, and other hydrological processes. The main aquifers located at the site are the Dakota and the Glen Canyon. There are 18 on-site groundwater monitoring wells to provide sufficient information on these aquifers if an accident were to occur during or before the development of the nuclear power plant. Further details on groundwater conditions are located in section 10.3.

10.1.2e Surface Hydrology & Flooding Potential

The surface hydrology and flooding potential are affected by the permeability of the soil. Chipeta soil has the property of slow permeability which influences the water flow on the surface. The movement of water ranges from medium to very high runoff. The runoff have no influence to water features such as ponds in the nearby area. All the water features have an inflow from rainfall and flash-floods, while little precipitation occurs. There is no influence of the Green River since the nuclear plant site is located approximately 300 feet above the river's elevation. Further details on surface hydrology and flooding potential are located in section 10.4.

10.1.2f Seismic Considerations

The seismic requirements of safety and security for the nuclear power plant site is regulated by the Nuclear Regulatory Committee (NRC). The assessment of the site location analyzes the nearby faults and vegetation to determine the seismic activity. The low topographic relief displays slope instability at a low and no indication of land sliding. The potential fault hazards considered within a 200 mile radius are considered for potential seismic activity. The Little Grand Valley fault provided concerns due to its vicinity to the site. However, all the faults were considered unable to provide sufficient ground motion to cause problems. Further details on the seismic activity and faults are located in section 10.5.

10.2 Soil Conditions

According to the second edition of *An Introduction to Geotechnical Engineering* by Holtz *et. all*, there are two main types of soil: coarse grained, or granular, and fine grained soil. The coarser the grain of a soil, the larger the individual particles in the soil skeleton. In a coarse soil, typically more than 50% of the grains by weight have a grain diameter of greater than 0.075 mm. Otherwise, the soil is classified as fine grained. Further, two individual subcategories divide each of those categories. The different types of coarse grained soil are gravel and sand. According to the UCSC, the division point is 4.75 mm [2], i.e. any particles with diameters between 0.75 mm and 4.75 mm are sand, and anything larger is gravel. The division between silt and clay for fine-grained particles depends less on the grain size than on the properties of the soil when it comes in contact with water. In general, clay particles are smaller than silt particles, but the main difference is that silt is not cohesive, but clay is, i.e. clay particles with enough water bond together to form a malleable mass, but silt particles do not demonstrate that adhesion even at high water contents [2].

10.2.1 Soil Classification

The main soil types found at the proposed location for the Blue Castle Nuclear Power Plant are the Chipeta-Badland and Ravola-Garley soil complexes. The area covered by those two complexes comprises more than half of the area of the available data for the location [3]. The Chipeta-Badland and Ravola-Garley complexes are labelled 031 and 143 in Figure 1, respectively. The Chipeta clay has a depth of roughly ten inches, measured from the surface to the top of the bedrock. The entirety of the Chipeta profile is a silty clay, with 92-100% of the soil grains classified as sand or finer and at least 73% silt or clay [3], according to the USCS. The Badland soil only has a two inch depth above the bedrock. It is entirely sand or finer, and similarly to the Chipeta soil, at least 73% of it is clay or silt [3].

The Ravola-Garley soil complex is slightly different than the Chipeta-Badland soil. According to the web soil survey published by the Natural Resources Conservation Service of the United States Department of Agriculture, the Ravola-Garley soil extends significantly deeper than the Chipeta-Badland, and it has a slightly higher percentage of coarse grained soils depending on the depth studied. Ravola soil extends to a depth of about five feet below the ground surface. It contains less than 14% gravel throughout its profile, and can be anywhere from 65% to 90% silt or clay. Therefore, it is still a fine-grained soil, but with a larger sand and gravel component than the Chipeta or the Badland. The Garley soil extends to a similar depth, but may be up to 43% gravel near the midpoint of its profile or 34% near the surface. Depending on the depth studied, Garley soil may be classified as coarse or fine grained. It has a sandy surface, a finer profile to about a foot of depth, and an even finer profile up to about three feet. There is a narrow band of coarse materials at about three feet of depth, and the rest of the soil down to a depth of five feet is a fine sand [3].

10.2.2 Collapsible Soil Analysis

Collapsible soil can be cause by two separate phenomenons. The first, is based on the structure of the soil. As clay is layered, it can form a microstructure that looks like a honeycomb. When saturated, the structure is overwhelmed by pore pressure and collapses. The second is caused by gaps in the soil when gypsum or calcium carbonate dissolve. As with the honeycomb structure, the thin layers between gaps can break when the soil is saturated. Thicker layers will break over time due to applied loads.

The proposed site for the power plant consists of mostly Chipeta soil. Chipeta soil can contain up to 30% of dissolvable soils. In this region, Gypsum content varies from 0-6% and lime content varies from 8-16% [3]. The wide range of variability makes it difficult to design a strong foundation that can adapt to the collapse of the soil.

10.2.2a Remediation

There are three forms of remediation for collapsible soils; soil replacement, compaction, and chemical stabilization. Soil replacement is very time consuming and costly. Compaction uses mechanical processes to force the air out of the soil by pushing the soil particles into the voids. This decreases the space available for settlement; however it does not address the solubility of gypsum and calcium carbonate. Even with compaction, significant settlement will occur after a heavy rainfall. Chemical stabilization is often the most cost efficient and effective method to strength collapsible soils caused by gypsum and calcium carbonate.

Chemical stabilization is created through adding lime or cement to the soil. Lime stabilization is susceptible to failure due to the high sulfate content. Type II cement is able to resist the corrosive nature of sulfates. 10-15% cement by dry weight is typically required for CH-CL soils [4]. For the best results, the amount of cement and the water content should be determined through laboratory tests. If the soil is too dry, the cement will not be able to undergo the proper chemical reactions to stabilize the soil. If the soil is too wet the cement will flow and settle at the bottom of the permeable layer before solidifying. This will only stabilize a small portion of the soil.

10.2.3 Expansive Soil Analysis

Expansive soils expand when in contact with sufficient amounts of water. Montmorillonite is one of the most expansive soils and is known for absorbing water and expanding to several times it original size. Underneath the Chipeta soil is a layer of Mancos Shale, which is known “to be both expansive and collapsible under load when wetted” [5]. The expansive shale is caused by Montmorillonite clay.

10.2.3a Remediation

Mancos Shale can be treated using cement or lime, but at different concentrations than what would be used to stabilize Chipeta soil. Testing is necessary to determine just how expansive the shale is and how much the expansiveness is reduced through chemical treatment. The other option is to drive piles below the active zone.

Granular pile anchor-foundation (GPAF) systems have been used to reduce heave for several years now. Granular piles are created by drilling a hole and then using a vibro-replacement technology to create a dense column of soil. The GPAF system adds a concrete pedestal to the bottom of the fill that is attached to a cable [6]. The cable must be pretensioned. The cable then puts the pile into tension and reduces heave by up to 90%, if extended below the active zone [7].

10.2.4 Frost Heave Analysis

Frost heave is caused when water is trapped in the soil and freezes. When water freezes, it expands, creating heave. When the ice melts, the soil settles quickly. The effects of this can been seen in roads, as pot holes. There are only 135 frost free days at the site; however, Chipeta soil only presents a small risk for frost action. Any frost heave can be easily countered by the weight of the structure.

10.3 Groundwater

Considerations for the groundwater table must be accounted for not only for geotechnical engineering properties, but monitoring is also required. This allows the detection of possible contaminants, that they may be dealt with appropriately in an adequate time and manner. Ground-water systems are dynamic and adjust continually to short-term and long-term changes in climate, ground-water withdrawal, and land use. Water-level measurements from observation wells are the principal source of information about the hydrology of the site and the effect on ground-water recharge, storage, and discharge. Long-term, systematic measurements of water levels provide essential data needed to evaluate changes in the groundwater table over time, and to develop ground-water models and forecast trends. Using this information, we are able to design, implement, and monitor the effectiveness of ground-water management and protection programs [8]. There are 18 on-site groundwater monitoring wells installed with depths ranging from 30-150 feet [9]

The site is located on the surface of a thick sequence of the Cretaceous-age Mancos Shale The shale is considered the upper confining unit to the Dakota-Glen Canyon aquifer system which are predominantly composed of thick sequences of poorly to well-consolidated conglomerate of sandstone, siltstone, and shale [9].The Dakota and Glen Canyon aquifers are the major aquifers in the system beneath the site, and are reported to be near 2000 feet below ground surface [9]. Mancos Shale is not commonly considered a groundwater aquifer, but has been recognized to store limited quantities of very low quality groundwater [9]. No groundwater source for cooling or non-cooling uses is available or planned for on-site.

10.4 Surface Hydrology & Flooding Potential

Geologic surveys in the area have found the top-most surface layer of the soil to consist mostly of Chipeta soil. Chipeta is common in Emery County, Utah and consists of very shallow, well drained, slowly permeable soils that formed in slope alluvium and/or colluvium derived from sedimentary rocks over residuum from the Mancos shale [10].

These soils are on gently sloping topography from NW to the SE. Chipeta is well drained with medium to very high runoff and slow permeability. The permeability of Chipeta soil: 0.43-1.4 micrometers/second [9]. There are no permanent water features located in the vicinity of the site, however located to the east are two very small ponds will not influence site area by means of seepage or permeability. All water features are fed by intermittent rainfall and flash floods. Little precipitation occurs in the area (less than 10 inches per year) [9].

The elevation of the Blue Castle site ranges from 4237 to 4370 feet in elevation, which is approximately 300 feet above the local elevation of the Green River. There are no dams are other upstream flooding concerns in the general area of the proposed site. Flood events in the past have not included Emery County or Grand County [11]. After an examination of topography, the site is expected to be outside of 100 and 150 year floodplains [11].

10.5 Seismic Considerations

The NRC is an independent agency of the United States government whose role is to protect public health and safety related to nuclear energy. It oversees reactor safety and site security. The NRC's requirements for seismic considerations are such that an analysis is required to provide adequate characterization of potential seismic sources in the site region, and development of expected ground motions, and possible geological deformation.

An assessment of possible tectonic surface deformation within the site area itself would be required. Below the site rests approximately 3000 feet of shale, mudstone, and siltstone of Mancos Shale. Bedrock is exposed at the surface and there is little native vegetation - these conditions are favorable for documenting an absence of surface faulting. The site lies within the northwestern part of the Paradox Basin geologic province which is characterized by northwest striking faults and surface deformation known to be related to subsurface movement of salt bodies. The under formed shale strata beneath the site, suggests a lack of salt-related ground deformation [11]. Topographic relief is the significance of change in elevation on the ground surface. Because of presence of low topographic relief on site, the likelihood of slope instability is very low, and there is an absence of any indication of land sliding.

An investigation of geologic and fault hazards within a radius of 200 miles of the site was also conducted. The U.S. Geological Survey identifies the following faults with possible movement within area of interest of the site [11]:

a) Ten Mile Graben Fault
b) Salt Valley and Cache Valley fault

c) Price River Fault
d) Moab Fault
e) Ryan Creek Fault
f) Sand Flat Graben Fault
g) Little Dolores River Fault
h) Southern Joes Valley Fault
i) East Joes Valley Fault
j) Little Grand Valley Fault

The Little Grand Valley fault is of particular concern for it is the closest mapped fault to the site; however, none of these faults are considered to be capable of a source of strong ground motions [11]. There are no faults within the site and due to their distance from the site, these faults do not pose a surface or subsurface deformation hazard. In addition to deformation, the movement of possible earthquakes must be considered.

Peak ground acceleration (PGA) is a measure of earthquake acceleration on the ground and an important input parameter for earthquake engineering. The NRC regulates that the PGA for a site are designed for 0.3g [11]. The expected peak ground acceleration for the site is 0.18g, which is within the acceptable range. It is expected that ground fluctuations will not pose a fatal flaw in the site location.

10.6 Conclusion

The proposed site comprises of two major soil types near the surface: Chipeta-Badland and Ravola-Garley soil complexes. Both complexes are classified by the USCS as cohesive, fined grained, sandy soils with the Ravola - Garley being slightly coarser and extends deeper into the ground. Because of the expansive nature of fined grained soils, special precautions must be met to ensure that the structural integrity of the reactor is not put in jeopardy because of an unstable foundation. It is recommended that superficial layers of the site be remediated chemically - by adding cement to the soil matrix, to bind together soil particles and effectively stabilize the soil foundation. Underneath the surface soil complex lies a thick layer of Mancos shale, which can stabilized similarly; however, the use of GPAFs are recommended. Because of its low topographic relief and low annual precipitation rate, slope instability is of little concern. Flood potential is low for the site is approximately 300 feet above the elevation of the green river. There are no faults within the site, nor are any of the faults within a 200 mile radius are expected to cause any ground disturbance or surface deformation. The proposed site meets NRC requirements for seismic considerations, and appears to be feasible location for a nuclear power plant.

10.7 References

[1] William E. Mulvey, "Soil and Rock Causing engineering Geologic Problems in Utah" *Utah Geologic Survey,* Utah Department of Natural Resources, 1992

[2] R. D. H. e. all, "An Introduction to Geotechnical Engineering" 2nd ed. Upper Saddle River, NJ: Pearson Education, Inc., 2011.

[3] "Web Soil Survey," United States Department of Agriculture, Aug. 8, 2014. [Online]. Available: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

[4] E.C. Lawton, "Soil Improvement and Stabilization: Non-Grouting Techniques" in *Practical Foundation Engineering Handbook*, 2nd Edition, edited by R.W. Brown, McGraw-Hill, 2001, sec 6A, pp. 6.279.

[5] C.S. Russell, "Geotechnical Report", Grand Junction Inc., Grand Junction, CO, rep. 2002.

[6] M.R. Madhav, "Granular Piles-Construction, Design and Behavior," J.N.T. University, Hyderabad, India. rep. Nov. 2013.

[7] A.N. Aljorany, S.F. Ibrahim, A.I. Al-Adly, "Heave Behavior of Granular Pile Anchor-Foundation System (GPA-Foundation System) in Expansive Soil," Journal of Engineering. vol. 20, Apr. 2014.

[8] Charles J. Taylor, William M. Alley "Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data" http://pubs.usgs.gov/circ/circ1217/pdf/circ1217_final.pdf

[9] Briefing for NRC Pre-Application Activities and Seismic Issues Involved with the Pending Blue Castle Project Early Site Permit http://uraniumwatch.org/bluecastle.earlysitepermit/bch_nrcmeeting_slides_intro.111027.pdf

[10] "Chipeta Series," National Cooperative Soil Survey, https://soilseries.sc.egov.usda.gov/OSD_Docs/C/CHIPETA.html Apr 2015.

[11] Turner, H Kyle "Report on preliminary site consultation," http://uraniumwatch.org/dwr_greenriverhearings_2010/mct_prelimsiteconultation.091120.pdf Apr 2015.

Appendix I: Classification Figures

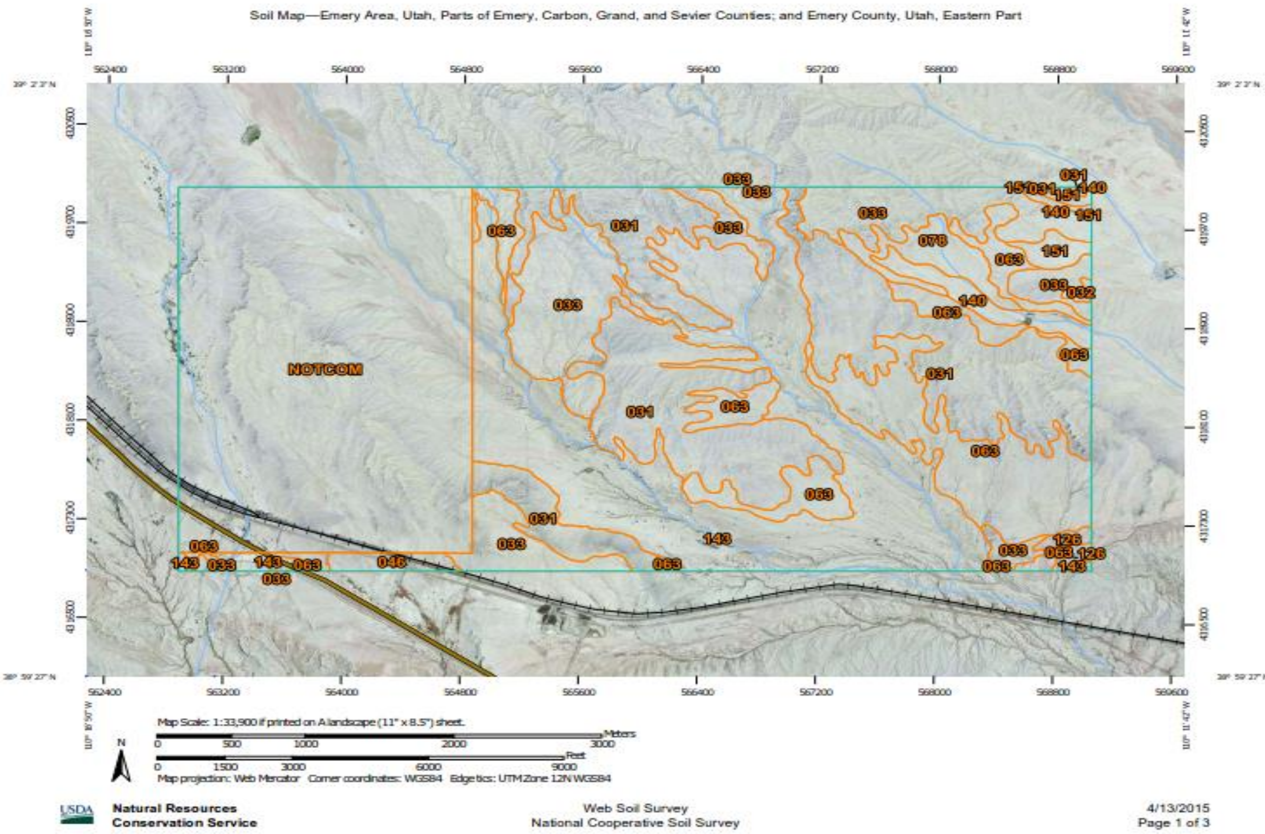


Figure 10.1: On site Soil Type [3].

Engineering Properties

Emery Area, Utah, Parts of Emery, Carbon, Grand, and Sevier Counties

[Absence of an entry indicates that the data were not estimated. This report shows only the major soils in each map unit]

Map symbol and soil name	Depth	USDA texture	Classification		Fragments		Percent passing sieve number--				Liquid limit	Plasticity index
			Unified	AASHTO	>10 Inches	3-10 Inches	4	10	40	200		
	In				*Pct*	*Pct*					*Pct*	
031:												
Chipeta	0-3	Silty clay loam	CH, CL	A-6, A-7-6	0	0	92-100	92-100	83-100	73-89	40-53	20-26
	3-9	Silty clay loam	CH, CL	A-6, A-7-6	0	0	100	100	87-97	77-87	40-51	20-26
	9-10	Parachannery silty clay, silty clay loam	CH, CL	A-7-6	0	0	100	100	93-100	88-98	44-54	24-30
	10-20	Bedrock	---	---	---	---	---	---	---	---	---	---
Badland	0-2	Clay, silty clay	CH, CL	A-7-6	0	0	100	100	83-100	73-93	49-68	29-44
	2-12	Bedrock	---	---	---	---	---	---	---	---	---	---
143:												
Ravola	0-5	Loam, silt loam	CL, CL-ML	A-4, A-6	0	0	86-100	85-100	82-100	65-89	24-37	7-16
	5-28	Loam, silt loam	CL	A-4, A-6	0	0	93-100	92-100	90-100	77-90	26-38	10-17
	28-33	Fine sandy loam, very fine sandy loam	CL, CL-ML	A-4, A-6	0	0	86-100	85-100	82-100	50-68	20-32	5-12
	33-65	Loam, silt loam	CL	A-4, A-6	0	0	93-100	92-100	85-100	72-90	25-37	9-17
Garley, reclaimed	0-2	Gravelly fine sandy loam	GC-GM, SC	A-2-4, A-6	0	0-10	66-85	64-84	57-82	33-50	23-31	7-11
	2-13	Fine sandy loam, very fine sandy loam	CL	A-4, A-6	0	0	86-100	85-100	83-100	50-64	24-31	8-11
	13-34	Loam, silt loam	CL	A-6	0	0	86-100	85-100	82-100	64-79	30-39	12-14
	34-38	Gravelly fine sandy loam	GC, GC-GM, SC	A-2-4, A-4	0	0-7	57-86	55-85	51-83	25-44	23-30	7-10
	38-60	Fine sandy loam, very fine sandy loam	CL, SC	A-4, A-6	0	0	86-100	86-100	78-97	46-59	24-31	8-11

USDA Natural Resources Conservation Service

Survey Area Version: 4
Survey Area Version Date: 08/08/2014

Page 1

Figure 10.2: Engineering Properties of Chipeta-Badland and Ravola-Garley soils [3].

Chapter 11

BCP Feasibility Report Conclusions

Abstract
This chapter summarizes individual chapters in the Report and offers a Decision Matrix Score regarding the feasibility of moving forward with further development on the Project.

11.1 Conclusion

A nuclear power plant provides several benefits to Utah's economy and energy supply. The potential to increase Utah's electricity production to twice its current yield is plausible with this new plant. The extra energy to the grid can be sold to neighboring states bolstering Utah's economy. Aside from the economic benefits, the current coal production, natural gas, and other fossil fuel harms the air quality and poses a threat to the local environment from the retrieval of fossil fuels. Nuclear power is an alternative to fossil fuels, however, the plant must satisfy specific criteria before entering the development stage. This report determines if the Blue Castle Nuclear Power Plant is feasible to pass regulations and be developed.

The security of the nuclear power plant is strictly regulated due to past events such as the attack against the United States on September 11, 2001. The security and regulations will be upheld to attain the public trust before approval to develop the nuclear power plant. Blue Castle will license the plant to another company that will maintain the integrity and security of the public and investors. The investments to move the project forward will be contributed from investors, taxpayers, and government for energy subsidies. In addition to security, an analysis of the reactor is significant to the feasibility of the development.

The nuclear reactor is an AP1000 type. The reactor is a third generation (3rd gen.) pressurized water reactor from Westinghouse's Nuclear division. Key features Westinghouse's 3rd gen. reactor is the design and its capabilities. The 3rd gen. is able to produce 1116 MWe of electricity. Which improved efficiency will require less fuel and produce less waste. The design is compact compared to earlier models. This reduces the amount of supplies that would be invested in the development of the facility. In addition to saving materials in structural development, the design has a passive safety functionality that does not require operation for 72 hours. The passive safety function maintains enough water to cool the core and control rods are positioned to work with gravity to stop the nuclear fission. These features from the new reactor improves the feasibility of the nuclear power plant being developed. Aside from the reactor, the design shows a degree of promise.

The design and layout of the Blue Castle Holdings (BCH) nuclear power plant is expected to be similar to other nuclear power plant designs. Of most importance is the nuclear island which houses the reactor and the containment building - the final barrier in case of failure and radioactive leakage. Other typical structures associated with the design are the cooling towers, discharge ponds, and onsite spent rod storage. The Vogtle nuclear power plant is a suitable example of what can be expected of the BCH site design.

Water is essential to the reactor for the high heat absorbance. The current design of the plant is intended to use water from a leased water rights. The water rights was originally for another coal burning power plant that was unbuilt in Kane and San Juan county water conservancy districts. The water will be put to beneficial use and subleased to Blue Castle instead of forfeiting the right to Kane and San Juan County; however, it is recommended that Blue Castle apply for its own water rights due to the rights being claimed if the need arises. The current lease pushes the plant to approval for development, but recommended to take additional steps in securing water rights for future security.

The water source for the nuclear power plant is the Green River. The water drawn will be placed in a sedimentation pond, which reduces the particulate matter from entering the system. The water transport system is highly rated and support the development of the nuclear power plant.

Environmental concerns will always need to be taken into consideration while dealing with a project of this size, and also regarding the potential consequences of a nuclear radiation leak. That being said, the proposed nuclear plant design will use only 2 percent of the Green River's volumetric flow, affecting the 30 million people downriver who use the river as a source of water. Once construction is complete, the plant will emit negligible amounts of CO_2 and other greenhouse gases into the atmosphere and can be considered carbon neutral. While it is almost certain that the facility will have some sort of effect on the environment, there are monitoring systems and protocols to detect, prevent and reduce any harmful effects to the environment.

If the plant is to be built, it must adhere to safety regulations set by the NRC and other governing agencies. Standard Operating Procedures outline conditions that must be met and or maintained, how work hazards are reported, as well as operation and safety protocols. Physical site security will be regulated by the NRC by use of private or public security firms. Cyber security is maintained by keeping all critical functions and processes independent of the online network.

Due to the relatively remote and unused land surrounding the Blue Castle Holdings site, it is a very suitable location for onsite storage of spent fuel rods without risk of contamination or failure. Both wet and dry storage may be effectively implemented at this site. It has been determined that the site is appropriate for the current treatment and disposal techniques of nuclear waste. The system developed for the waste water treatment and disposal are secure and feasible. The waste treatment and disposal lays out the proper framework to satisfy demands and prevention of accidents. Aside from waste and disposal, the foundation stability is a potential hazard.

The nuclear power plant site is located in an area with two major soil types. The Chipeta-Badland and Ravola-Garley soil complexes are classified as cohesive, fine-grained, sandy soils. The Ravola-Garley is coarser in comparison to the Chipeta-Badland. Due to the expansive nature of both soils, precautions must be taken to maintain the structural integrity and security. The soil types are unstable, thus a recommendation to stabilize the soil by chemical binding. The chemical stabilization is an addition of cement to the soil mixture. There is no concern for flood potential impacts and seismic influences to adversely affect the soil foundation or stabilization. With proper surface soil stabilization techniques, the site is deemed a suitable location for a nuclear power plant.

The investigations in areas above for the Blue Castle Nuclear Power Plant Project proposes the development to move forward and begin construction. A decision matrix was constructed in all investigations and each section passes with a total score of 38.5 out of 45. The details of the matrix can be seen in Table 11.1. Each individual score is based on a scale of one to five, where one is not feasible and five is very feasible. The project passes in all areas with few recommendations in the water rights, soil foundation and reactor design. Yet, lacks support in Utah's energy demand and environmental concerns. If the score was below 30, a high recommendation towards canceling the project. However, the project exceeded the value which will satisfy many of the security of communities affected by the Green River. The project design is thorough and developed which will satisfy the integrity and security of the people investing the project.

Table 11.1: Feasibility of each aspect of the plant.

Criteria	**Decision Matrix Score**
Utah's Energy Demand and Resources: Does this solution resolve Utah's energy demand?	2
Reactor Design: Does the reactor supply appropriate energy and apply enough safety factors?	5
Structural Design: Is the structure equipped to ensure the safety of surrounding communities and their workers	5
Water Rights Secure: Does the project have an appropriate amount of water allocated to not adversely affect nearby communities?	5
Water System Design: Is the drainage and channeling systems to draw and expense water satisfy the safety regulations?	4
Environmental Impact: Does the nuclear power plant adversely affect the local environment and pose a threat towards future generations?	3.5
Security Protocols: Does the security systems enable protection of national threat and cyber warfare towards information about nuclear power?	5
Waste Disposal and Treatment: Does the disposal treatment and storage satisfy the safety of the workers and storage vicinity?	4
Geotechnical Investigation: Does the foundation and recommendation support the structure and prevent costly corrective measure in the future?	5
Total out of 45	38.5